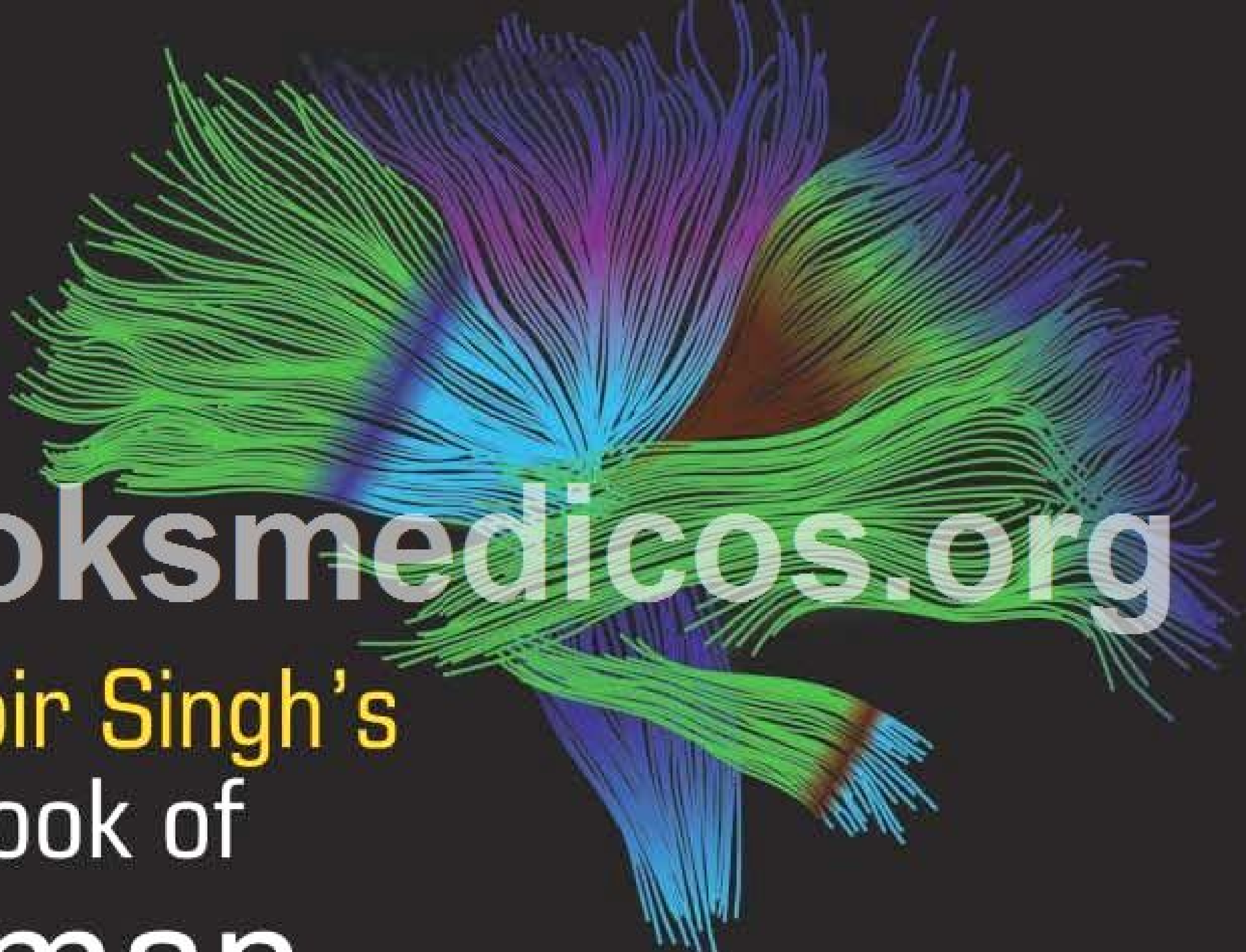

Inderbir Singh's

Textbook of Human Neuroanatomy

(Fundamental and Clinical)

Revised & Edited by
Pritha S Bhuiyan
Lakshmi Rajgopal
K Shyamkishore

NINTH EDITION

JAYPEE

Inderbir Singh's

Textbook of

HUMAN NEUROANATOMY

Late Professor Inderbir Singh
(1930–2014)

Tribute to a Legend

Professor Inderbir Singh, a legendary anatomist, is renowned for being a pillar in the education of generations of medical graduates across the globe. He was one of the greatest teachers of his times. He was a passionate writer who poured his soul into his work. His eagle's eye for details and meticulous way of writing made his books immensely popular amongst students. He managed to become enmeshed in millions of hearts in his lifetime. He was conferred the title of Professor Emeritus by Maharishi Dayanand University, Rohtak.

On 12th May 2014, he has been awarded posthomously with Emeritus Teacher Award by National Board of Examination for making invaluable contribution in teaching of Anatomy. This award is given to honour legends who have made tremendous contribution in the field of medical education and their work had vast impact on the education of medical graduates. He was a visionary for his times and the legacies he left behind are his various textbooks on gross anatomy, neuroanatomy, histology and embryology. Although his mortal frame is not present amongst us, his genius will live on forever.

Inderbir Singh's

Textbook of HUMAN NEUROANATOMY

(Fundamental and Clinical)

Ninth Edition

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Preface to the Ninth Edition

Professor Inderbir Singh has been a doyen in the field of Anatomy, and he has been looked upon as a guide and mentor by many students and teachers. So, it is indeed a great honour for us to edit the ninth edition of 'Inderbir Singh's Textbook of Human Neuroanatomy (*Fundamental and Clinical*). While editing this book has provided us an opportunity to revisit neuroanatomy, we have enjoyed this relook thoroughly.

To highlight what the students should learn from each chapter, 'Specific Learning Objectives' have been added. A comprehensive rearrangement of chapters has been done to make it easy for the students to understand the subject. Important clinical conditions are given as 'Clinical Correlation' in Boxes. Validated 'Multiple Choice Questions' have been added at the end of each chapter for self-assessment. New diagrams and photographs of dissected and plastinated specimens have been incorporated to make it reader friendly. New tables and flow charts have been inserted for making comprehension of neuroanatomy easy. The chapter on 'Imaging Techniques of the Central Nervous System' is updated completely keeping in mind the emerging trends in newer imaging techniques.

We are grateful to the Dean, Seth GS Medical College and KEM Hospital, for giving us the permission to edit this book. We are also thankful to Dr HD Deshmukh, Professor and Head, Department of Radiology for providing us CT scans and MRI scans. Our special acknowledgement to Mr. Prashant Jadhav for helping us with the photography. Our special thanks to all our students for making us take up this challenging task despite our academic and administrative responsibilities. We thank our family members for their continued support.

We hope that this edition will be useful to the students and teachers interested in neuroanatomy, and we welcome feedback from the readers to improve future editions.

Pritha S Bhuiyan, Lakshmi Rajgopal, K Shyamkishore

Foreword
(*to the Eighth Edition*)

My tryst with Neuroanatomy began in earnest as a postgraduate. But the seeds were sown as an undergraduate 1st year medical student. Today, as I stand on the verge of superannuation, having taught neuroanatomy for the last 40 years, I have been asked to write a foreword for Prof. Inderbir Singh's revised and updated reprint of 8th edition of the *Textbook of Human Neuroanatomy* for the undergraduate medical students which brings me to a full circle. I tried to recall, as an undergraduate, what is it that would have enticed me to read a neuroanatomy book. As I began pouring through the pages of Prof. Inderbir Singh's textbook, I found the answers—the easy readable style, the sifting of the essentials for a student to comprehend a majorly complex subject and the simple, easily reproducible illustrations. It is these qualities which form the backbone of this treatise that seem to have attracted the student to this book and made it a popular reading for the 1st year medical student for the last so many years.

Prof. Inderbir Singh's unending zeal and love for the students has made us see eight editions of the book with each one adding a new facet. In this revised and updated reprint of eighth edition too one sees many more illustrations for better understanding of the subject. I am sure the students are going to find as always that the book is updated, explanatory and relevant to meet their requirements.

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Preface to the Eighth Edition

I have great pleasure in presenting the **eighth edition** of TEXTBOOK OF HUMAN NEUROANATOMY.

As in previous editions, the main effort has been to present a complicated subject in as simple a manner as possible. The major problem that faces the author of any student textbook is to decide just how much to include out of the limitless volume of information available. Some facts are such that no student can afford to be without them. However, these essentials are often wrapped up in a huge mass of detail which often serves only to obscure the important principles relevant to future clinical studies. It is for this reason that, in this edition, essential matter is clearly demarcated from more advanced detail. Clinical matter is similarly demarcated.

In this edition the book has been given a **strong clinical orientation** which will appeal specially to advanced students.

I am much obliged to Shri Jitendar P Vij, Group Chairman, M/s Jaypee Brothers Medical Publishers (P) Ltd, New Delhi, for being always extremely helpful and accommodating. His hard work and pleasant nature make him a delight to work with.

I continue to be obliged to Prof SC Srivastava, and Dr RK Yadav for very kindly providing a number of photographs.

As always, I am deeply indebted to readers who have sent words of encouragement and suggestions for improvement. I am grateful to all students who have read this book, because without them the book would have no reason to exist.

Inderbir Singh

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Chapter 1

Introduction to Nervous System

Specific Learning Objectives

At the end of learning, the student shall be able to:
- Specify the divisions of nervous system
- Describe the structure of a typical neuron
- Classify neurons, nerve fibres and neuroglia
- Describe myelination
- Describe nerve injury, Wallerian degeneration
- Explain the anatomical basis of various neurological lesions

The human body consists of numerous tissues and organs, which are diverse in structure and function, yet they function together and in harmony for the well-being of the body as a whole. It is obvious that there has to be some kind of influence that monitors and controls the working of different parts of the body. Although there are other mechanisms that help in such control (for example hormones), the overwhelming role in directing the activities of the body rests with the nervous system. Neuroanatomy is the study of the structural aspects of the nervous system. It cannot be emphasized too strongly that the study of structure is meaningless unless correlated with function.

DIVISIONS OF NERVOUS SYSTEM

The nervous system may be divided into the ***central nervous system*** **(CNS)**, made up of the brain and spinal cord, the ***peripheral nervous system*** **(PNS)**, consisting of the peripheral nerves and the ganglia associated with them, and the ***autonomic nervous system*** **(ANS)**, consisting of the ***sympathetic*** and the ***parasympathetic nervous systems*** (Figures 1.1 and 1.2) (Table 1.1). The brain consists of the ***cerebrum, diencephalon***, ***midbrain***, ***pons***, ***cerebellum*** and ***medulla oblongata***. The midbrain, pons, and medulla oblongata together form the ***brainstem***. The medulla oblongata is continuous below with the spinal cord (Figure 1.2).

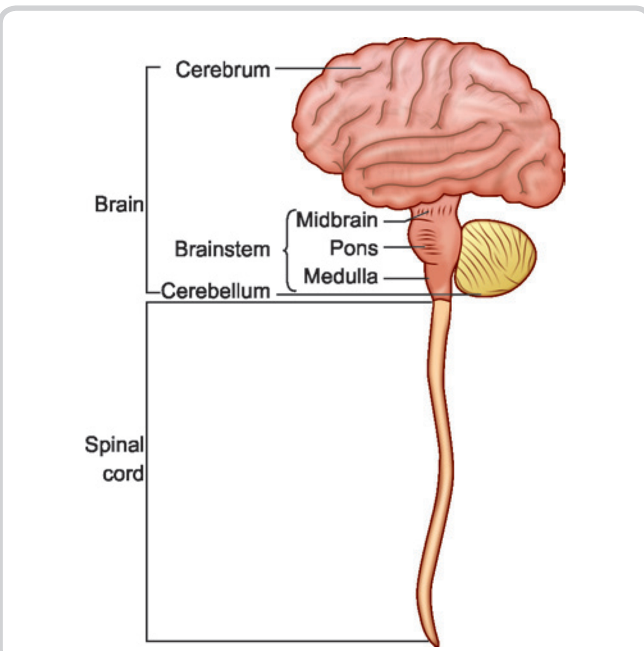


Figure 1.1: Anatomical divisions of the nervous system. The central nervous system consists of the brain and spinal cord. The peripheral nervous system consists of cranial nerves and spinal nerves.

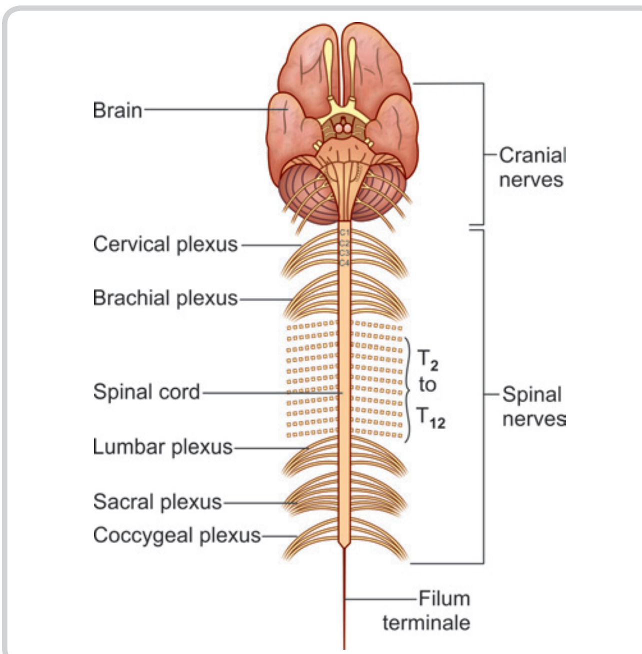


Figure 1.2: Diagram showing parts of the central nervous system

Table 1.1 | Divisions of Nervous System

Nervous system	Central	Brain (encephalon)	Forebrain (Prosencephalon)	Telencephalon (cerebrum)
				Diencephalon
			Midbrain (Mesencephalon)	
			Hindbrain (Rhombencephalon)	Metencephalon (pons and cerebellum)
				Myelencephalon (medulla oblongata)
		Spinal cord (myelon)		
	Peripheral	Cranial nerves	I	Olfactory
			II	Optic
			III	Oculomotor
			IV	Trochlear
			V	Trigeminal
				Abducens
			VII	Facial
			VIII	Vestibulocochlear
			IX	Glossopharyngeal
			X	Vagus
			XI	Spinal accessory
			XII	Hypoglossal
		Spinal nerves	Cervical	C1 to C8
			Thoracic	T1 to T12
			Lumbar	VI
			Sacral	S1 to S5
			Coccygeal	Co

The peripheral nerves include those that supply skin, muscles, and joints of the body wall and limbs, and those that supply visceral structures, for example, heart, lungs, stomach, etc. Each of these sets of peripheral nerves is intimately associated with the brain and spinal cord. Peripheral nerves attached to the brain are called ***cranial nerves***, and those attached to the spinal cord are called ***spinal nerves*** (Figure 1.2). The nerves supplying the body wall and limbs are often called ***craniospinal nerves***. The nerves supplying the viscera, along with the parts of the brain and spinal cord related to them, constitute the ANS. The ANS is subdivided into two major parts—the ***sympathetic*** and the ***parasympathetic*** nervous systems.

TISSUES CONSTITUTING NERVOUS SYSTEM

The nervous system is made up, predominantly, of tissue that has the special property of being able to conduct impulses rapidly from one part of the body to another.

The specialized cells that constitute the functional units of the nervous system are called ***neurons***.

Within the brain and spinal cord, neurons are supported by a special kind of connective tissue that is called ***neuroglia***.

Nervous tissue, composed of neurons and neuroglia, is richly supplied with blood. It was earlier thought that lymph vessels were not present in the brain. However, recently it has been shown that interstitial fluid from brain

parenchyma drains through lymphatics, that travel along the wall of the arterioles and arteries of the brain.

The nervous system of man is made up of innumerable neurons. The total number of neurons in the human brain is estimated to be more than 1 trillion. The neurons are linked together in a highly intricate manner. It is through these connections that the body is made aware of changes in the environment or of those within itself and appropriate responses to such changes are produced, for example, in the form of movement or in the modified working of some organ of the body. The mechanisms for some of these relatively simple functions have come to be known as a result of a vast amount of work done by numerous workers for over a century. There is no doubt that higher functions of the brain, like those of memory and intelligence, are also to be explained on the basis of connections between neurons, but as yet, little is known about the mechanisms involved. Neurons are, therefore, to be regarded not merely as simple conductors, but as cells that are specialized for the reception, integration, interpretation, and transmission of information.

Note: Nerve cells can convert information obtained from the environment into codes that can be transmitted along their axons. By such coding, the same neuron can transmit different kinds of information.

STRUCTURE OF A TYPICAL NEURON

Neurons vary considerably in size, shape, and other features. However, most of them have some major features in common and these are described below.

A neuron consists of a ***cell body*** that gives off a number of ***processes*** called ***neurites*** (Figure 1.3A and B).

The cell body is also called the soma or ***perikaryon***. Like a typical cell, it consists of a mass of cytoplasm surrounded by a cell membrane. The cytoplasm contains a large central nucleus (usually with a prominent nucleolus), numerous mitochondria, lysosomes, and a Golgi complex (Figure 1.3B). In the past, it has often been stated that centrioles are not present in neurons, but studies with the electron microscope (EM) have shown that centrioles are present.

In addition to these features, the cytoplasm of a neuron has some distinctive characteristics that are not seen in other cells.

The cytoplasm shows the presence of a granular material that stains intensely with basic dyes. This material is the ***Nissl substance*** (also called Nissl bodies or granules) (Figure 1.3C). When examined with the EM, these bodies are seen to be composed of rough surfaced endoplasmic reticulum (Figure 1.3B). The presence of abundant granular endoplasmic reticulum is an indication of the high level of protein synthesis in the neurons. The proteins are needed for production of neurotransmitters and enzymes as well as maintenance and repair.

Another distinctive feature of neurons is the presence of a network of fibrils permeating the cytoplasm. These ***neurofibrils*** are seen, with the EM, to consist of microfilaments and microtubules (Figure 1.3D). The centrioles present in neurons may be concerned with the production and maintenance of microtubules.

Some neurons contain pigment granules (for example, neuromelanin in neurons of the substantia nigra). Aging neurons contain a pigment, lipofuscin (made up of residual bodies derived from lysosomes).

Neurites

The processes arising from the cell body of a neuron are called ***neurites***. These are of two kinds. Most neurons give off a number of short branching processes called ***dendrites*** and one longer process called an ***axon***.

The dendrites are characterized by the fact that they terminate near the cell body. They are irregular in thickness and Nissl granules extend into them (Figure 1.3C). They bear numerous small spines that are of variable shape. Some additional features of dendrites are:

- Dendrites can be distinguished immunocytochemically from axons because of the presence of microtubule associated protein (MAP-2), not present in axons.
- Dendritic spines vary in size and shape. Some spines contain aggregations of smooth endoplasmic reticulum (in the form of flattened cisternae with associated dense material). The complex is referred to as the spine apparatus.
- Actin filaments are present in dendritic spines.

The axon may extend for a considerable distance away from the cell body. The longest axons may be as much as a meter long. Each axon has a uniform diameter and is devoid of Nissl substance (Figure 1.3C).

In addition to these differences in structure, there is a fundamental functional difference between dendrites and axons. In a dendrite, the nerve impulse ***travels towards the cell body*** whereas in an axon the impulse travels ***away from the cell body***. A summary of the differences between dendrite and axon is shown in Table 1.2.

Axon Hillock and Initial Segment

The axon is free of Nissl granules. The Nissl-free zone extends for a short distance into the cell body. This part of the cell body is called the ***axon hillock***. The part of the axon just beyond the axon hillock is called the ***initial segment*** (Figure 1.3B and C).

The axon hillock and the initial segment of the axon are of special functional significance. This is the region where action potentials are generated (spike generation), resulting in conduction along the axon. The initial segment is unmyelinated. It often receives axoaxonal synapses that are inhibitory. The plasma membrane, here, is rich in voltage-sensitive channels.

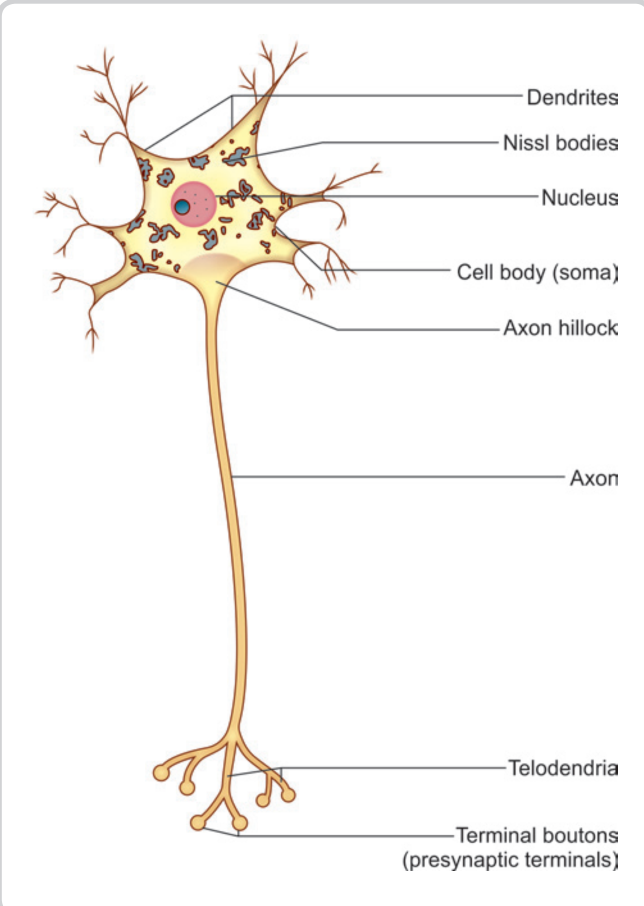


Figure 1.3A: Diagram showing the main parts of a typical neuron

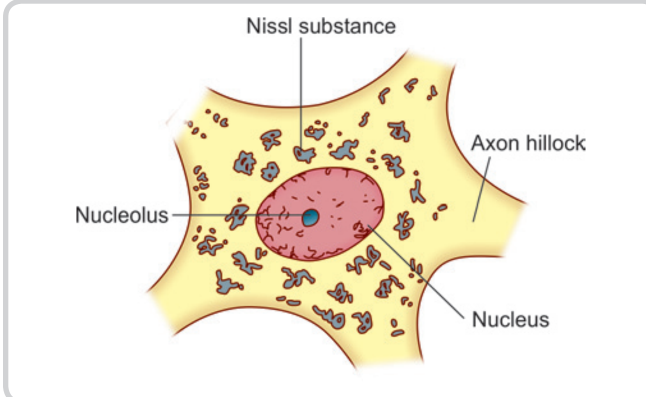


Figure 1.3C: Neuronal cell body shows Nissl substance.

Note: The Nissl substance is not present in the axon and in the region of axon hillock but extends into proximal dendrites

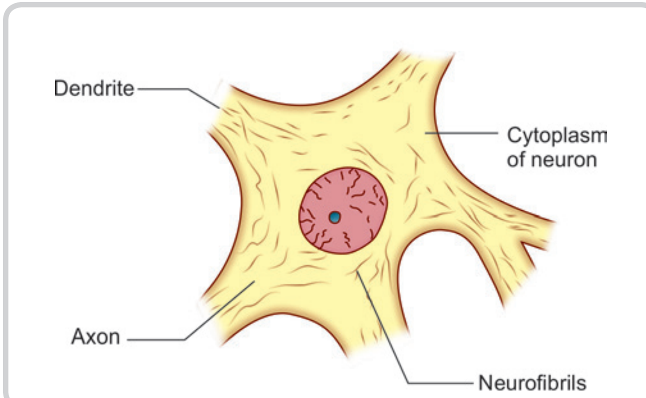


Figure 1.3D: Neuronal cell body shows neurofibrils.

Note: The neurofibrils extend into both axons and dendrites

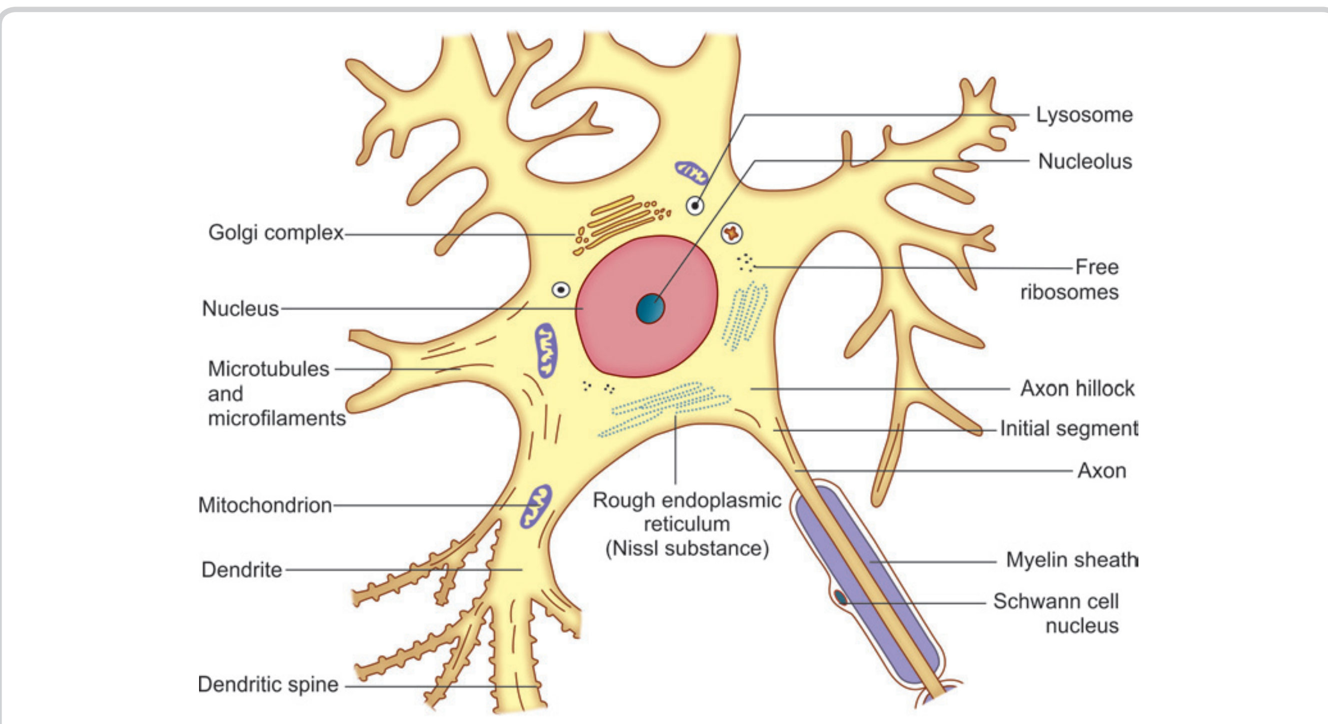


Figure 1.3B: Schematic representation of some structural features of neuron as seen by electron microscope

Table 1.2 | Difference between Axons and Dendrites

Axon	Dendrites
Axon is a single, long, thin process of a nerve cell, which terminates away from the nerve cell body	Dendrites are multiple, short, thick and tapering processes of the nerve cell which terminate near the nerve cell body
Axon rarely branches at the right angle (axon collaterals) but ends by dividing into many fine processes called axon terminals.	Dendrites are highly branched. Their branching pattern forms a dendritic tree.
It has uniform diameter and smooth surface	The thickness of dendrite reduces as it divides repeatedly. Its surface is not smooth, but it bears many small spine-like projections for making synaptic contacts with the axons of other nerve cells
It is free of Nissl granules	Nissl granules are present in dendrites
The nerve impulses travel away from the cell body	The nerve impulses travel towards the cell body

Termination of Axon

An axon may give off a variable number of branches. Some branches, which arise near the cell body and lie at right angles to the axon are called ***collaterals***. At its termination, the axon breaks up into a number of fine branches called ***telodendria*** that may end in small swellings (***terminal boutons*** or ***bouton terminaux***) (Figure 1.3A). An axon (or its branches) can terminate in two ways. Within the CNS, it always terminates by coming in intimate relationship with another neuron, the junction between the two neurons being called a ***synapse***. Outside the CNS, the axon may end in relation to an effector organ (for example, muscle or gland), or may end by synapsing with neurons in a peripheral ganglion.

Axoplasmic Flow

The cytoplasm of neurons is in constant motion. Movement of various materials occurs through axons. This ***axoplasmic flow*** takes place both away from and towards the cell body. The flow away from the cell body is greater. Some materials travel slowly (0.1–2 mm a day) constituting a ***slow transport***. In contrast, other materials (mainly in the form of vesicles) travel 100–400 mm a day constituting a ***rapid transport***.

Slow transport is unidirectional, away from the cell body. It is responsible for flow of axoplasm (containing various proteins) down the axon. Rapid transport is bidirectional and carries vesicular material and mitochondria. Microtubules play an important role in this form of transport. Retrograde axoplasmic flow may carry neurotropic viruses (see below) along the axon into the neuronal cell body.

Axoplasmic transport of tracer substances introduced experimentally can help to trace neuronal connections.

Clinical Correlation

Role of axoplasmic transport in spread of disease

Some infections, which affect the nervous system travel along nerves.

Contd...

- Rabies is a disease (often fatal), caused by a bite of a rabid dog (and some other animals, including monkeys). The saliva of an infected animal contains the rabies virus. The virus travels from the site of the bite to the CNS, along nerves by reverse axoplasmic flow and causes infection there. As this means of transport is slow, there is a delay of a few days between the bite and appearance of symptoms. The duration of this delay depends on the length of the nerve fibres concerned. A bite on the face produces symptoms much faster than on the foot.
- The virus of poliomyelitis is also transported (from the gastrointestinal tract) to the nervous system through reverse axoplasmic flow.
- In contrast, tetanus travels from the site of infection to the brain along the endoneurium of nerve fibres.

Neuropil

Many regions of the brain and spinal cord are occupied by a complex meshwork of axon terminals, dendrites and processes of neuroglial cells. This meshwork is called the ***neuropil***.

CLASSIFICATION OF NEURONS

Anatomical Classification

Variation in the Shape of Neuronal Cell Bodies

Neurons vary considerably in the size and shape of their cell bodies (somata) and in the length and manner of branching of their processes (Figures 1.4 and 1.5). The cell body varies in diameter from about 5 µm, in the smallest neurons, to as much as 120 µm in the largest ones. The shape of the cell body is dependent on the number of processes arising from it.

The most common type of neuron gives off several processes, and the cell body is, therefore, ***multipolar***. Some neurons have only one axon and one dendrite and are ***bipolar*** (Figures 1.4 and 1.5).

Another type of neuron has a single process (which is highly convoluted). After a very short course, this process

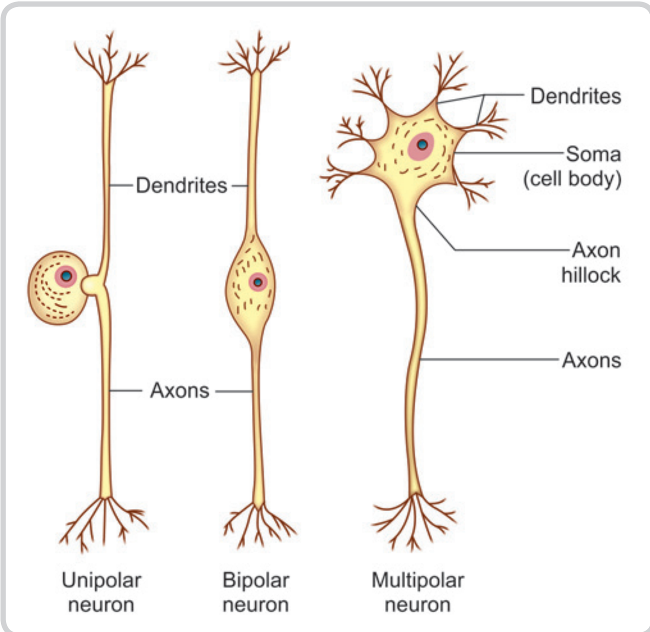


Figure 1.4: Unipolar, bipolar, and multipolar neurons

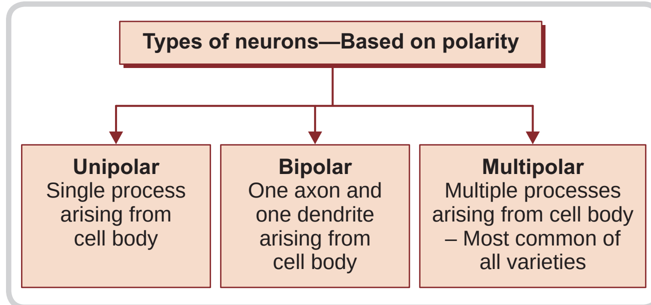


Figure 1.5: Types of neurons—anatomical classification

Note: In unipolar neurons, after a very short course the process divides into two. One of the divisions represents the axon, and the other is functionally a dendrite, but its structure is indistinguishable from that of an axon. This neuron is described as unipolar, but from a functional point of view, it is to be regarded as bipolar. To avoid confusion on this account, this kind of neuron has been referred to as a pseudounipolar neuron.

divides into two. One of the divisions represents the axon; the other is functionally a dendrite, but its structure is indistinguishable from that of an axon. This neuron is described as ***unipolar***, but from a functional point of view, it is to be regarded as bipolar. To avoid confusion on this account, this kind of neuron has been referred to as a ***pseudounipolar*** neuron in the past, but this term has now been discarded. Depending on the shapes of their cell bodies, some neurons are referred to as ***stellate*** (star-shaped) or ***pyramidal***.

In addition to the variations in size and shape, the cell bodies of neurons may show striking variations in the appearance of the Nissl substance. In some neurons, the Nissl substance is very prominent and is in the form of large clumps. In some others, the granules are fine and uniformly distributed in the cytoplasm, while yet other neurons show gradations between these extremes. These differences are correlated with function.

Variations in Axons

The length of the axon arising from the cell body of a neuron is also subject to considerable variability.

- ***Golgi type I*** neurons have long axons and connect remote regions.
- ***Golgi type II*** neurons or ***microneurons/interneurons*** have short axons that end near the cell body. These are often inhibitory in function (Table 1.3).
- Very rarely, a neuron may not have a true axon, for example, ***amacrine*** neurons of the retina.

As stated earlier, axons also differ in the nature of the sheaths covering them, some of them being myelinated and others unmyelinated. Axons also show considerable variation in the diameter of their cross-sections.

Variations in Dendrites

Dendrites arising from a neuronal cell body vary considerably in number and in the extent and manner of branching. They also differ in the distribution of spines on them. These characteristics are of functional importance. The ***area*** occupied by the dendrites of a neuron is referred to as its ***dendritic field***.

The field may be ***spherical*** (as in stellate cells), ***hemispherical, disk-like, conical, or flat***. In some neurons (for example, pyramidal), there may be two separate dendritic fields. Apart from shape, there is considerable variability in the extent of the dendritic field. Some neurons (for example, Golgi neurons of the cerebellum) have dendritic fields covering a very wide area. More than

Table 1.3 | Morphological Classification of Neurons

Morphology	Location and example
According to polarity	
• Unipolar/pseudounipolar	Posterior root ganglia of spinal nerves, sensory ganglia of cranial nerves
• Bipolar	Retina, sensory ganglia of cochlear and vestibular nerves
• Multipolar	Motor neurons of anterior grey column of spinal cord, autonomic ganglia
According to size of nerve fibre	
• Golgi type I	Purkinje cells of cerebellum, Anterior horn cells of spinal cord, Pyramidal cells of cerebral cortex
• Golgi type II	Cerebral and cerebellar cortex

80% of the neuronal surface area (excluding the axon) may be situated on the dendritic tree. The frequency of branching of dendrites is correlated with the number of synapses on them. In some neurons, the dendritic spines may number several thousand. Finally, it may be emphasized that the dendritic tree is not a '***fixed***' entity, but may undergo continuous remodeling. This affords a basis for modification of neuronal behaviour.

NERVE FIBRES

Axons (and some dendrites, which resemble axons in structure) constitute what are commonly called ***nerve fibres***.

The bundles of nerve fibres found in CNS are called as ***tracts,*** while the bundles of nerve fibres found in PNS are called ***peripheral nerves***.

Basic Structure of Peripheral Nerve Fibres

Each nerve fibre has a central core formed by the axon. This core is called the ***axis cylinder***. The plasma membrane surrounding the axis cylinder is the ***axolemma***.

The axis cylinder is surrounded by a myelin sheath. This sheath is in the form of short segments that are separated at short intervals called the ***nodes of Ranvier***. The part of the nerve fibre between two consecutive nodes is the ***internode***.

Each segment of the myelin sheath is formed by one Schwann cell.

Outside the myelin sheath, there is a thin layer of Schwann cell cytoplasm and an external lamina (similar to the basal lamina of epithelium). This layer of cytoplasm and external lamina is called the ***neurilemma***. Neurilemma is important in the regeneration of peripheral nerves after their injury.

Note: Such neurilemma is absent in oligodendrocytes that form myelin sheath in CNS. Hence, regeneration in the CNS is not possible.

Each nerve fibre is surrounded by ***endoneurium*** (Figure 1.6). This is a layer of connective tissue. The endoneurium holds adjoining nerve fibres together and facilitates their aggregation to form bundles or ***fasciculi***.

Each fasciculus is surrounded by the ***perineurium*** (Figure 1.6) that is a thicker layer of connective tissue. The perineurium is made up of layers of flattened cells separated by layers of collagen fibres. The perineurium probably controls diffusion of substances in and out of axons.

A very thin nerve may consist of a single fasciculus, but usually a nerve is made up of several fasciculi. The fasciculi are held together by the epineurium. This is a fairly dense layer of connective tissue that surrounds the entire nerve.

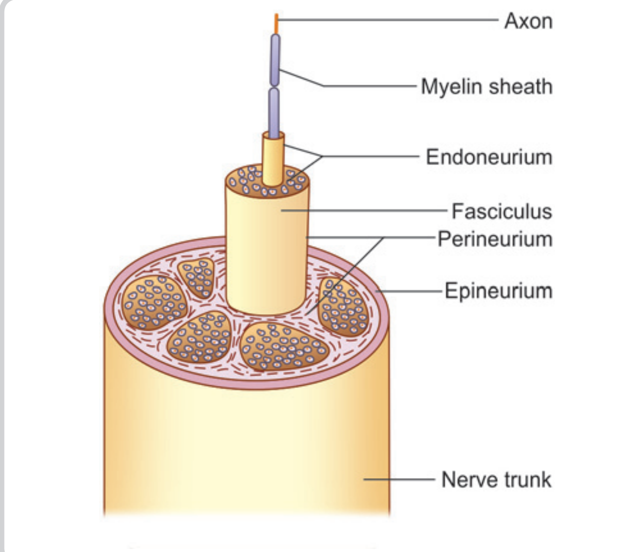


Figure 1.6: Diagram showing the connective tissue supporting nerve fibres of a peripheral nerve

Clinical Correlation

- The epineurium contains fat that cushions nerve fibres. Loss of this fat in bedridden patients can lead to pressure on nerve fibres and paralysis.
- Blood vessels to a nerve travel through the connective tissue that surrounds it. Severe reduction in blood supply can lead to ***ischemic neuritis*** and pain.

Blood-nerve Barrier

Peripheral nerve fibres are separated from circulating blood by a blood-nerve barrier. Capillaries in nerves are non-fenestrated and their endothelial cells are united by tight junctions. There is a continuous basal lamina around the capillary. The blood-nerve barrier is reinforced by cell layers present in the perineurium.

Classification of Peripheral Nerve Fibres

According to Function

- Some nerve fibres carry impulses from the spinal cord or brain to peripheral structures like muscle or gland; they are called ***efferent*** or ***motor*** fibres. Efferent fibres are axons of neurons, the cell bodies of which are located in the grey matter of the spinal cord or of the brainstem
- Other nerve fibres carry impulses from peripheral organs to the brain or spinal cord. These are called ***afferent*** fibres. Many (but not all) afferent fibres are concerned in the transmission of sensations like touch, pain, etc. They are, therefore, also called ***sensory*** fibres. Afferent nerve fibres are processes of neurons that are located (as a rule) in sensory ganglia.

In the case of spinal nerves, these ganglia are located on the dorsal nerve roots. In the case of cranial nerves, they

are located on ganglia situated on the nerve concerned (usually near its attachment to the brain). The neurons in these ganglia are usually of the unipolar type. Each unipolar neuron gives off a peripheral process, which passes into the peripheral nerve forming an afferent nerve fibre. It also gives off a central process that enters the brain or spinal cord.

From what has been said above, it will be clear that the afferent nerve fibres in peripheral nerves are functionally dendrites. However, their histological structure is exactly the same as that of axons.

According to Area of Innervation

According to the area of innervation, the nerve fibres within the spiral nerves may be classified into the following types:

- ***Somatic sensory fibres:*** They convey impulses from skin, bones, muscles, and joints to the CNS.
- ***Somatic motor fibres:*** They carry impulses from CNS to the skeletal muscles.
- ***Visceral sensory fibres:*** They convey impulses from visceral organs and blood vessels to the CNS.
- ***Visceral motor fibres:*** (also called *autonomic motor fibres*) They carry impulses from CNS to the cardiac muscle, glands, and smooth muscles within the viscera.

According to Diameter and Velocity of Conduction

In a transverse section across a peripheral nerve, it is seen that the nerve fibres vary considerably in diameter. Fibres of larger diameter are myelinated while those of smallest diameters are unmyelinated. Large fibres of larger diameter conduct impulses more rapidly than those of smaller diameter. Various schemes for classification of nerve fibres on the basis of their diameter and their conduction velocity have been proposed. The best known classification is as follows (Table 1.4).

Type A

The fastest conducting fibres are called type A fibres. Their conduction velocity is 12–120 m/s, and their diameter varies from 2 μm to 20 μm. They are myelinated.

Type A fibres are further divided (in descending order of diameter and conduction velocity) into four subtypes: alpha (A α), beta (A β) gamma (A γ), and delta (A δ). Type A fibres perform both motor and sensory functions as follows:

Motor type A fibres

- Aα fibres supply extrafusal fibres in skeletal muscle.
- Aγ fibres supply intrafusal fibres in muscle spindles.
- Aδ fibres are collaterals of Aα fibres (to extrafusal fibres) that innervate some intrafusal fibres.

Sensory type A fibres

- A α sensory fibres carry impulses from encapsulated receptors in skin, joints, and muscle. They include primary sensory afferents from muscle spindles (also called Group Ia fibres), Golgi tendon organs (also called Group Ib fibres), and secondary afferents from spindles, touch, and pressure (also called Group II fibres). Some of them carry impulses from the gut.
- Aδ sensory fibres (also called Group III fibres) are afferents from thermoreceptors and nociceptors (pain receptors).

Type B

Type B fibres have a conduction velocity of 3–15 m/s and their diameter is 1–5 μm. They are myelinated. They are either preganglionic autonomic efferent fibres (motor) or afferent fibres from skin and viscera, and from free nerve endings in connective tissue of muscle (also called Group III fibres).

Type C

In contrast to type A and type B fibres, type C fibres are unmyelinated. They have a conduction velocity of 0.5–2 m/s, and their diameter is 0.2–1.5 μm. These are postganglionic autonomic fibres and some sensory fibres conveying pain. These include nociceptive fibres from connective tissue of muscle (also called Group IV fibres). Some fibres from thermoreceptors and from viscera also fall in this category.

Table 1.4 | Classification of Fibres in the Peripheral Nerves

Fibre Type	Function	Diameter (μm)	Velocity (m/s)	Sensory classification
A α	Muscle spindle, annulo-spiral ending Golgi tendon organ Somatic motor	13–20	70–120	Ia Ib –
A β	Muscle spindle, flower-spray ending Touch, pressure	6–12	30–70	II II
A γ	Motor to muscle spindles	3–6	15–30	–
A δ	Pain, cold, touch	2–5	12–30	III
B	Preganglionic autonomic	1–5	3–15	–
C	Pain, temperature, itch, tickle Postganglionic autonomic	0.2–1.5	0.5–2	IV –

Unmyelinated axons are numerous in dorsal nerve roots and in cutaneous nerves. All postganglionic autonomic nerve fibres are unmyelinated, although preganglionic nerves are myelinated fibres.

MYELINATED AND NONMYELINATED NERVE FIBRES

A myelinated nerve fibre is one that is surrounded by a myelin sheath. The myelin sheath is formed by oligodendrocyte in the CNS and by Schwann cell in the PNS.

Small diameter axons, for example, those of the ANS and small pain fibres, are simply enveloped by the cytoplasm of Schwann cells. These nerve fibres are said to be ***non-myelinated***.

Myelin Sheath

The nature of myelin sheath is best understood by considering the mode of its formation (Figure 1.7).

An axon lying near a Schwann cell invaginates into the cytoplasm of the Schwann cell. In this process, the axon comes to be suspended by a fold of the cell membrane of the Schwann cell. This fold is called the ***mesaxon*** (Figure 1.8).

In some situations, the mesaxon becomes greatly elongated and comes to be spirally wound around the axon, which is thus surrounded by several layers of cell membrane. Lipids are deposited between adjacent layers of the membrane. These layers of the mesaxon, along with the lipids, sphingomyelin, form the ***myelin sheath***.

Outside the myelin sheath, a thin layer of Schwann cell cytoplasm and an external lamina persists to form an additional sheath, which is called the ***neurilemma*** (also called the neurilemmal sheath or Schwann cell sheath).

An axon is related to a large number of Schwann cells over its length. Each Schwann cell provides the myelin sheath for a short segment of the axon (Figure 1.9). At the junction of any two such segments, there is a short gap in the myelin sheath. These gaps are called the ***nodes of Ranvier***. The part of the nerve fibre between two such nodes is called the ***internode***. The length of the internode is greater in thicker fibres and shorter in thinner ones. It varies from 150 to 1500 µm.

The nerve fibres within a nerve frequently branch. When they do so, the bifurcation always lies at a node.

Nodes of Ranvier

The nodes of Ranvier have great physiological importance. When an impulse travels down a nerve fibre, it does not proceed uniformly along the length of the axis cylinder, but jumps from one node to the next. This is called ***saltatory conduction***.

In unmyelinated neurons, the impulse travels along the axolemma. Such conduction is much slower than saltatory conduction and consumes more energy.

Myelination does not occur simultaneously in all axons. A myelinated tract becomes fully functional only after its fibres have acquired myelin sheaths.

Nerve fibres are not fully myelinated at birth. Myelination is rapid during the first year of life and becomes much slower thereafter. This is to be correlated with the gradual ability of an infant to perform more complicated actions.

Further Consideration of the Structure of the Myelin Sheath

From Figure 1.10, it will be seen that each layer of plasma membrane helping to form the myelin sheath has an internal or cytoplasmic surface that comes in contact with the internal surface of the next layer, and an external surface that meets the external surface of the next layer. When the myelin sheath is examined with the higher magnifications of the electron microscope (EM), it shows alternate thick and thin lines. The thick lines (called

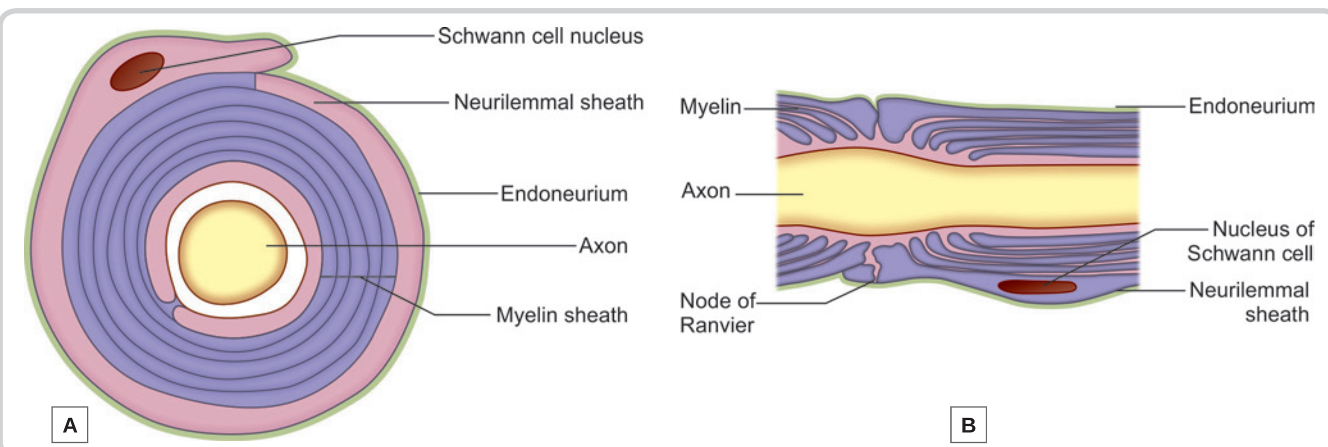


Figure 1.7: Myelin sheath. (**A**) Transverse section (**B**) Longitudinal section

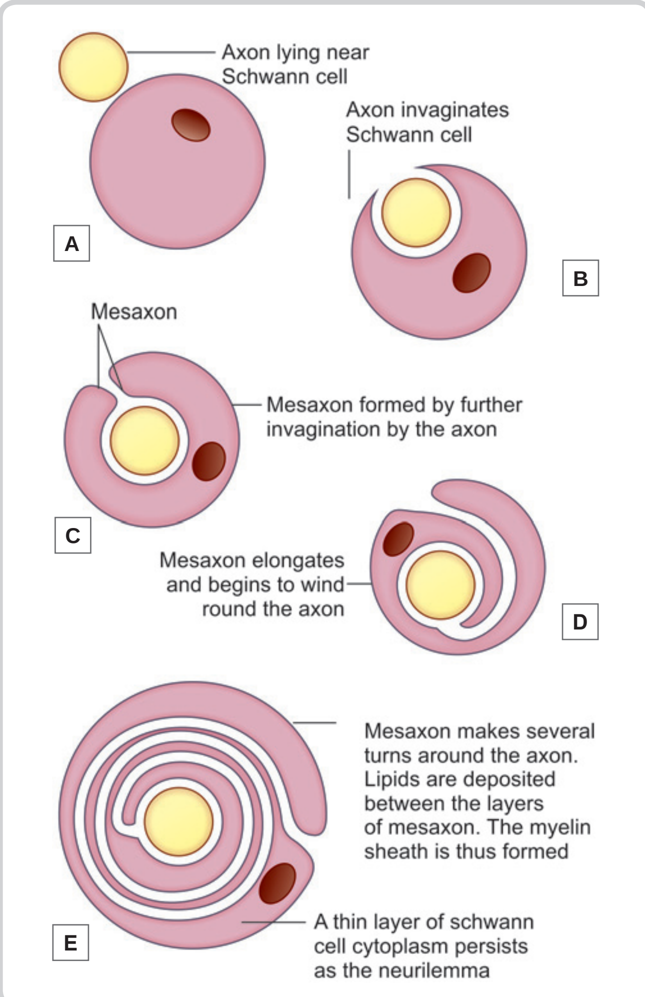


Figure 1.8: Stages in the formation of the myelin sheath by a Schwann cell—The axon, which first lies near the Schwann cell (**A**), invaginates into its cytoplasm (**B and C**), and comes to be suspended by a mesaxon. The mesaxon elongates and comes to be spirally wound around the axon (**D and E**). Lipids are deposited between the layers of the mesaxon.

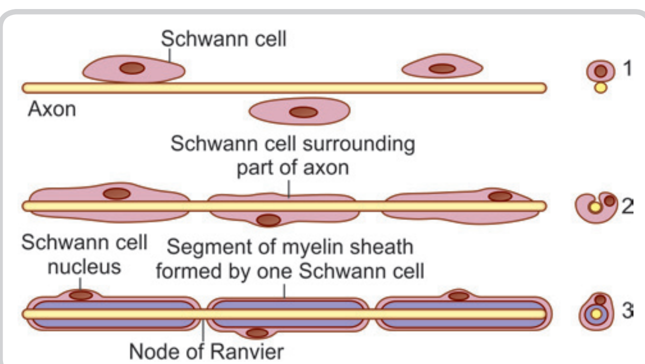


Figure 1.9: Scheme to show that each Schwann cell forms a short segment of the myelin sheath. The small figures at the extreme right are transverse sections through the nerve fibre, at the corresponding stages

period lines or ***major dense lines***) represent the fused cytoplasmic surfaces of two adjacent layers of the plasma membrane, whereas the thin lines (called ***intraperiod lines*** or ***minor dense lines***) represent the fused external surfaces of two adjacent membranes. Some other terms of interest are shown in Figure 1.10.

Incisures of Schmidt Lanterman

With the light microscope, oblique clefts are often seen in the myelin sheath (Figure 1.11). These clefts are called the ***Schmidt Lanterman clefts***. EM studies show the clefts to be areas where adjoining layers of Schwann cell plasma membrane (forming the myelin sheath) have failed to fuse leaving a layer of Schwann cell cytoplasm that passes spirally around the axon in the position of the period line and a spiral space through which the perineural space communicates with the periaxonal space in the position of the intraperiod line. This space provides a path for passage of substances into the myelin sheath and axon, from the space around the nerve fibre. The clefts enlarge greatly when a nerve fibre undergoes Wallerian degeneration.

Composition of Myelin Sheath

Myelin contains protein, lipids, and water. The main lipids present include cholesterol, phospholipids, and glycos-phingolipids. Other lipids are present in smaller amounts.

Clinical Correlation

Myelination can be seriously impaired, and there can be abnormal collections of lipids, in disorders of lipid metabolism. Various proteins have been identified in myelin sheaths and abnormality in them can be the basis of some neuropathies.

The composition and structure of myelin sheaths formed by oligodendrocytes show differences from those formed by Schwann cells. The two are different in protein content and can be distinguished by immunocytochemical methods. As damage to neurons within the CNS is not followed by regeneration, oligodendrocytes have no role to play in this respect. In multiple sclerosis, myelin formed by oligodendrocytes undergoes degeneration, but that derived from Schwann cells is spared

Functions of the Myelin Sheath

- The presence of a myelin sheath increases the velocity of conduction (for a nerve fibre of the same diameter).
- It reduces the energy expended in the process of conduction.
- It is responsible for the colour of the white matter of the brain and spinal cord.

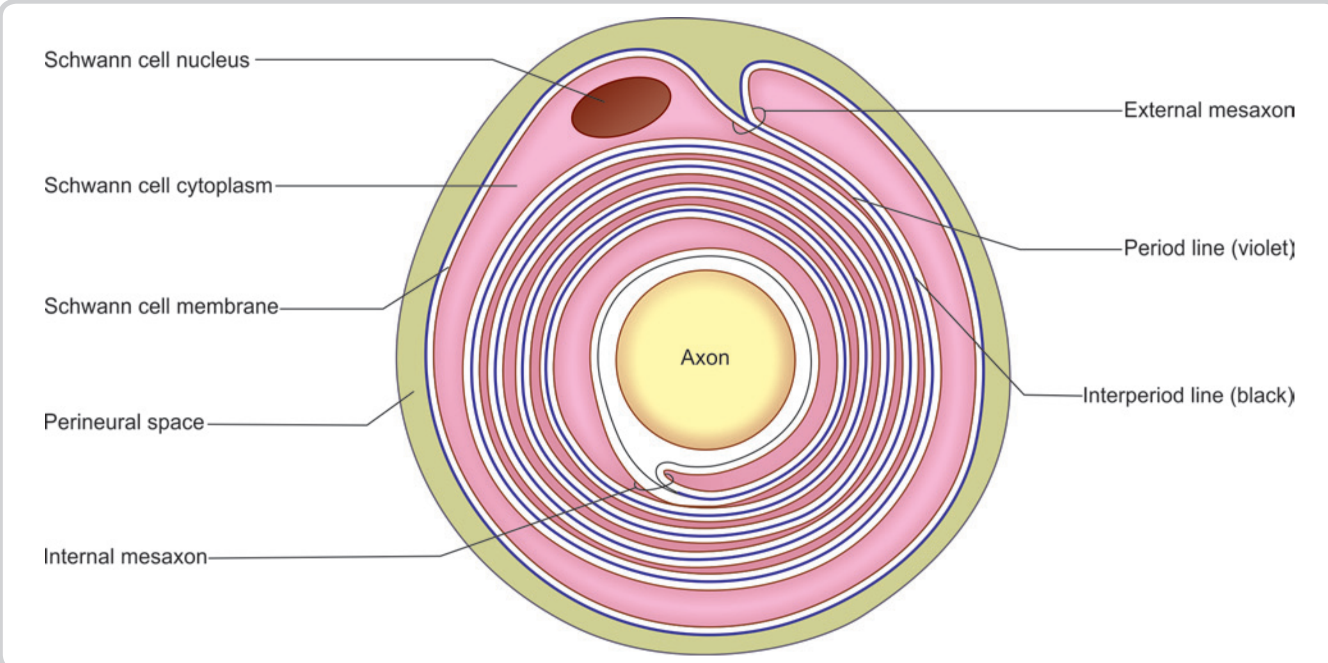


Figure 1.10: Scheme to explain the significance of period and intraperiod lines seen in the myelin sheath as viewed under electron microscope

Nonmyelinated Fibres

There are some axons, which are devoid of myelin sheaths and examples include postganglionic autonomic fibres. The nonmyelinated fibres are also surrounded by Schwann cells. These ***unmyelinated axons*** invaginate into the cytoplasm of Schwann cells, but the mesaxon does not spiral around them (Figure 1.12). Another difference is that several such axons may invaginate into the cytoplasm of a single Schwann cell.

In unmyelinated neurons, the impulse travels along the axolemma. Such conduction is much slower than saltatory conduction and consumes more energy.

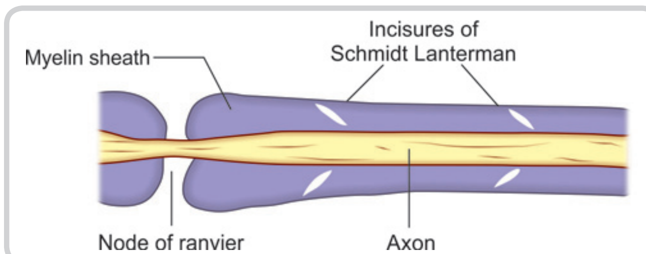


Figure 1.11: Incisures of Schmidt Lanterman

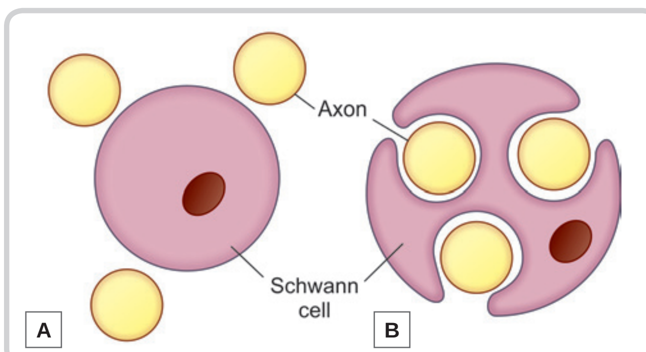


Figure 1.12: Relationship of unmyelinated axons to a Schwann cell

MYELINOGENESIS

Myelinogenesis is the process of sequential myelination around nerve fibres of the nervous system. The myelination process allows action potentials to propagate faster. Thus there is better connectivity within brain regions allowing the brain to specialize further. Myelination begins in the third trimester of intrauterine life and continues up to almost the fourth decade of postnatal life!

The myelination of peripheral motor roots is completed within the first month of postnatal life, the sensory roots takes a longer time and complete their myelination in six months. The pyramidal tracts (for voluntary motor activity) and the striatal pathways (for automatic associated movements) complete their myelination by two to three years. However, the fine co-ordination of movements which require the cortico-ponto-cerebellar circuit, complete their myelination only by the fourth year. Teaching a nursery child or play-school child to write, and expect the writing to be neat, is fundamentally against myelinogenesis!

Sensory thalamic radiations myelinate at different times. The optic radiation complete myelination by six months; the somaesthetic radiation by one year; the

auditory radiation is completed only by three years. Although reticulospinal pathway for automatic breathing starts functioning (and hence myelinated) at birth, the entire myelination of the reticular system is completed only in the second decade (during adolescence).

Cerebral cortical myelination continues to third to fourth decade of life. The motor cortex myelinates first followed by somatosensory cortex. Association cortices myelinate late. The limbic lobe of cingulate gyrus, the inferior temporal lobe for long term memory and the prefrontal cortex governing personality are the last areas to complete their myelination.

GREY AND WHITE MATTER

Sections through the spinal cord or through any part of the brain show certain regions that appear whitish, and others that have a darker greyish colour. These constitute the ***white*** and ***grey matter,*** respectively.

Microscopic examination shows that the cell bodies of neurons are located only in grey matter that also contains dendrites and axons starting from or ending on the cell bodies. Most of the fibres within the grey matter are unmyelinated.

On the other hand, the white matter consists predominantly of myelinated fibres. It is the reflection of light by myelin that gives this region its whitish appearance.

Neuroglia and blood vessels are present in both grey and white matter.

The arrangement of the grey and white matter differs at different regions in the brain and spinal cord. In the spinal cord and brainstem, the white matter is on the outside, whereas the grey matter forms one or more masses embedded within the white matter. In the cerebrum and cerebellum, there is an extensive, but thin, layer of grey matter on the surface. This layer is called the ***cortex***. Deep to the cortex, there is white matter, but within the latter, several isolated masses of grey matter are present.

Isolated spherical masses of grey matter present anywhere in the CNS are referred to as ***nuclei*** (red nucleus, oculomotor nucleus). As grey matter is made of cell bodies of neurons (and the processes arising from or terminating on them), nuclei can be defined as groups of cell bodies of neurons present within the CNS.

Aggregations of the cell bodies of neurons found outside the CNS are referred to as ***ganglia***.

Some neurons are located in ***nerve plexuses*** present in close relationship to some viscera. These are referred to as ***ganglionated plexuses***.

The axons arising in one mass of grey matter terminate very frequently by synapsing with neurons in other masses of grey matter. The axons connecting two (or more) masses of grey matter are frequently numerous enough to form recognizable bundles. Such aggregations of fibres are called ***tracts***.

Larger collections of fibres are also referred to as ***funiculi***, ***fasciculi,*** or ***lemnisci***. A lemniscus is a ribbon like band. Large bundles of fibres connecting the cerebral or cerebellar hemispheres to the brainstem are called ***peduncles***.

Aggregations of processes of neurons outside the CNS constitute ***peripheral nerves***.

BASIC NEURONAL ARRANGEMENTS

The nerve fibres that make up a peripheral nerve can be divided into two major types as follows:

- Fibres that carry impulses from the CNS to an ***effector organ*** (e.g. muscle or gland) are called ***efferent*** or ***motor*** fibres.
- Fibres that carry impulses from peripheral structures (e.g. skin) to the CNS are called ***afferent fibres***. Some afferent fibres carry impulses that make us conscious of sensations like touch or pain. Such fibres may, therefore, be called ***sensory fibres***. Other afferent fibres convey information, which is not consciously perceived, but is necessary for reflex control of various activities of the body.

Both afferent and efferent fibres can be further classified on the basis of the tissues supplied by them. The tissues and organs of the body can be broadly divided into two major categories—***somatic*** and ***visceral***.

Somatic structures are those present in relation to the body wall (or soma). They include the tissues of the limbs (which represent a modified part of the body wall). Thus, the skin, bones, joints, and striated muscles of the limbs, and body wall are classified as somatic.

Visceral structures, in contrast, are those that make up the internal organs like the heart, lungs, or stomach. These include the lining epithelia of hollow viscera and smooth muscle.

A distinction between somatic and visceral structures may also be made on embryological considerations.

- Structures developing from specialized areas of ectoderm, e.g. the retina and membranous labyrinth, are classified as somatic while the epithelium of the tongue (and taste buds), which is of endodermal origin is classified as visceral.
- Striated muscle may be derived, embryologically, from three distinct sources. These are:
  - The somites developing in the paraxial mesoderm
  - The somatopleuric mesoderm of the body wall
  - The mesoderm of the branchial arches

The musculature of the limbs and body wall develops partly from somites and partly *in situ* from the mesoderm of the body wall. The nerves supplying this musculature are classified as somatic. The muscles that move the eyeball, and the muscles of the tongue are also derived from somites and the nerves supplying them are, therefore,

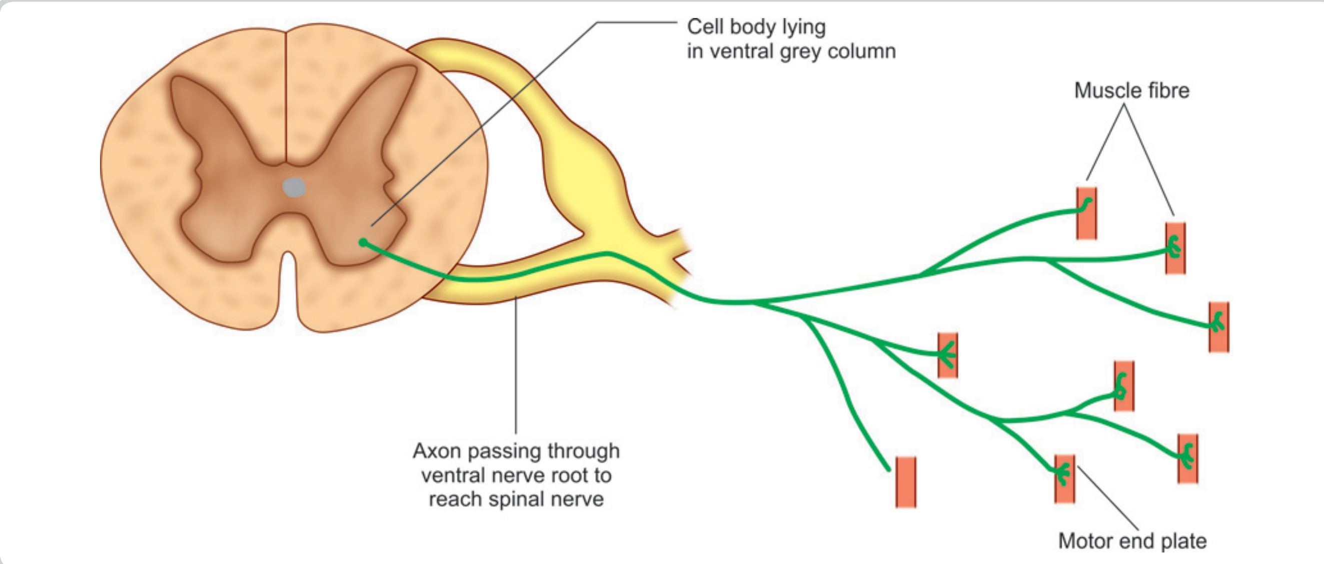


Figure 1.13: Scheme to show the typical arrangement of a somatic efferent neuron

also classified as somatic. However, striated muscle that develops in the mesoderm of the branchial arches is classified as visceral. Hence, the muscles of the face, the muscles of mastication, and the muscles of the pharynx and larynx are regarded as visceral.

Keeping in view the distinction between afferent and efferent fibres on one hand and somatic and visceral structures on the other, fibres in peripheral nerves can be divided into four broad categories.

These are:
- ***Somatic efferent***
- ***Visceral efferent***
- ***Somatic afferent***
- ***Visceral afferent***

With the exception of somatic efferent fibres, each of the categories named above is subdivided into a ***general*** and a ***special*** group. Thus, there are a total of seven ***functional components*** as follows:

- ***Somatic efferent*** (or ***somatomotor, GSE)*** fibres supply striated muscles of the limbs and body wall. They also supply the extrinsic muscles of the eyeballs and the muscles of the tongue.
- ***General visceral efferent*** fibres (also called ***visceromotor fibres, GVE***) supply smooth muscle and glands. The nerves to glands are called ***secretomotor*** nerves.
- ***Special visceral efferent (SVE)*** fibres supply striated muscle developing in branchial arch mesoderm. They are frequently called ***branchial efferent*** or ***branchiomotor*** fibres. The muscles supplied include those of mastication and of the face, pharynx, and larynx.
- ***General somatic afferent (GSA)*** fibres are those that carry:
  - ***Sensations*** of touch, pain, and temperature from the skin (***exteroceptive impulses***)
  - ***Proprioceptive impulses*** arising in muscles, joints, and tendons conveying information regarding movement and position of joints
- ***Special somatic afferent (SSA)*** fibres carry impulses of:
  - Vision
  - Hearing
  - Equilibrium
- ***General visceral afferent (GVA)*** fibres (also called visceral sensory fibres) carry sensations, e.g. pain from viscera (***visceroceptive*** sensations).
- ***Special visceral afferent (SVA)*** fibres carry the sensation of taste.

A typical spinal nerve contains fibres of the four general categories. The special categories are present in cranial nerves only.

Somatic Efferent Neurons

These neurons carry nerve impulses from CNS to striated muscles (Figure 1.13).

In the spinal cord, the cell bodies of these neurons lie in the ventral grey column. They are often referred to as anterior horn cells. The neurons are large and multipolar and their Nissl substance is prominent. They are designated as ***α-motor neurons*** to distinguish them from smaller anterior horn cells called ***γ-motor neurons***.

The axon of a somatic efferent neuron leaves the spinal cord through a ventral nerve root to enter the spinal nerve concerned. During its course through the spinal nerve (and its branches), the axon divides into a variable number of branches, each one of which ultimately ends by supplying one muscle fibre. The region of junction between a terminal branch of the axon and the muscle fibre has a special structure and is called the ***motor end plate*** or ***neuromuscular junction*** (Figure 1.14).

Motor Unit

Depending on the number of branchings, one anterior horn cell supplies a variable number of muscle fibres. One anterior horn cell and the muscle fibres supplied by it constitute one ***motor unit*** (Figure 1.14). In large muscles, where strength of contraction is more important than precision, a motor unit may contain up to 2000 muscle fibres. On the other hand, in muscles where precision is all important (e.g. in muscles of the eyeball), the motor unit may supply as few as six fibres.

The somatic efferent fibres of cranial nerves are axons of neurons, the cell bodies of which lie in somatic efferent nuclei in the brainstem. Their axons pass through the third, fourth, and sixth cranial nerves to supply the extrinsic muscles of the eyeballs and through the twelfth cranial nerve to supply muscles of the tongue.

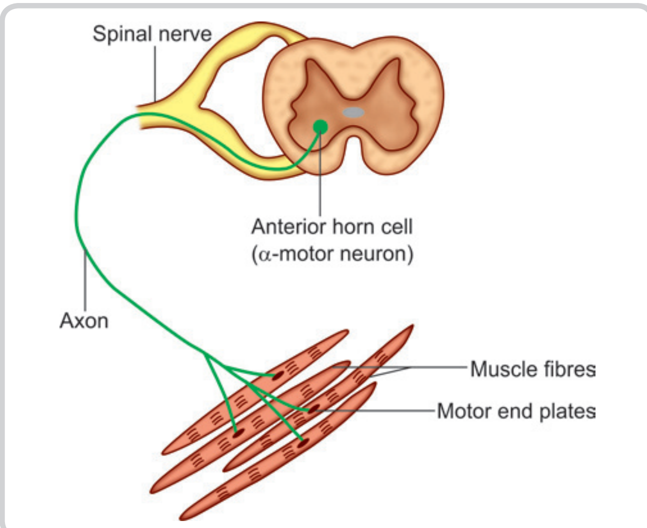


Figure 1.14: Schematic diagram to show a motor unit consisting of a number of muscle fibres innervated by a single motor neuron

Special Visceral Efferent Neurons (Branchiomotor Neurons)

These are seen only in relation to cranial nerves. The cell bodies of these neurons are located in the branchial efferent nuclei of the brainstem. Their axons pass through the fifth, seventh, ninth, tenth, and eleventh cranial nerves to supply striated muscle derived from the branchial arches. The relationship of these neurons to striated muscle is the same as that of somatic efferent neurons.

General Visceral Efferent Neurons

These are the neurons that constitute the autonomic nervous system (sympathetic and parasympathetic). They supply smooth muscle or glands. The nerves to glands are called ***secretomotor*** nerves. The pathway for the supply of smooth muscle or gland always consists of two neurons that synapse in a ganglion (Figure 1.15). The first neuron carries the impulse from the CNS to the ganglion and is, therefore, called the ***preganglionic*** neuron. The second neuron carries the impulse from the ganglion to smooth muscle or gland and is called the ***postganglionic*** neuron.

The cell bodies of preganglionic neurons of the sympathetic nervous system are located in the lateral grey column of the spinal cord, in the thoracic and upper two lumbar segments (Figure 1.15). Their cell bodies are multipolar but are smaller than those of somatic efferent neurons. The Nissl substance in them is also less prominent. The axons leave the spinal cord through the

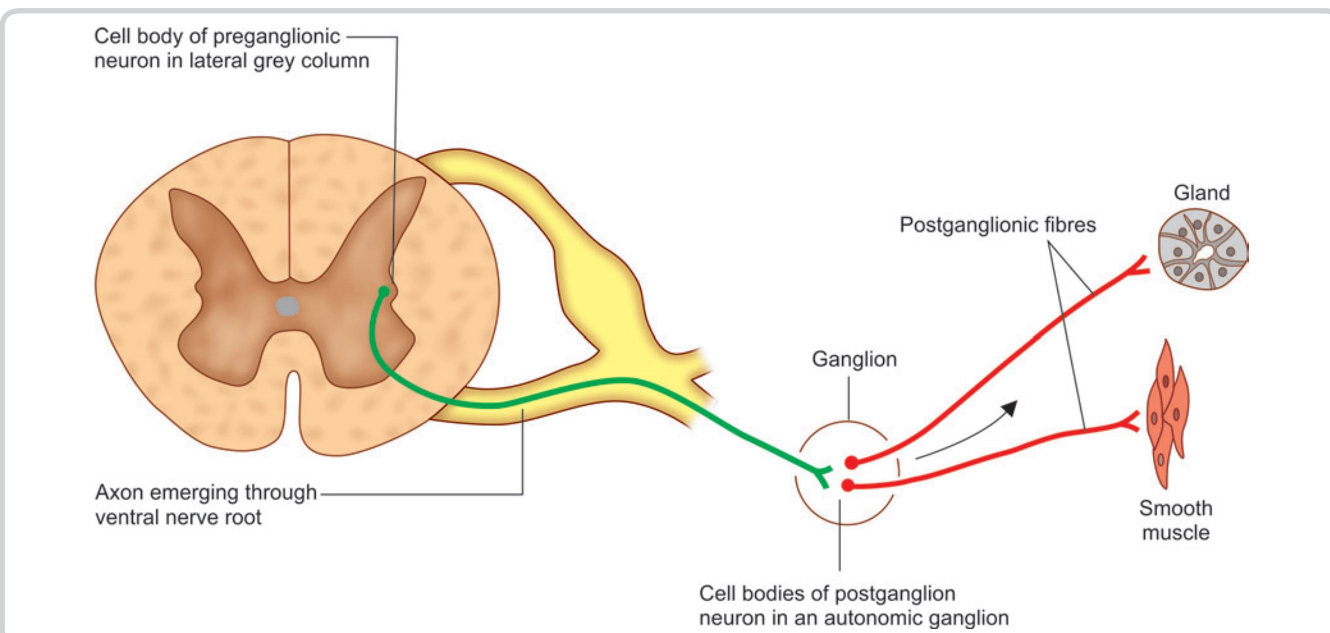


Figure 1.15: Scheme to show the typical arrangement of a general visceral efferent neuron

anterior nerve roots of spinal nerves and terminate in a sympathetic ganglion. The cell bodies of postganglionic neurons are located in sympathetic ganglia and in some cases, in peripherally situated ganglia and, plexuses. The axons of these postganglionic neurons terminate in relation to smooth muscle in the walls of blood vessels and in viscera. They also supply the arrectores pilorum muscles of the skin and give a secretomotor supply to sweat glands.

The cell bodies of preganglionic neurons of the parasympathetic nervous system are located in two different situations.

- One group is located in the lateral grey column of the spinal cord in the second, third, and fourth sacral segments. Their axons end in peripheral ganglia (or plexuses) situated in intimate relationship to pelvic viscera. These ganglia contain the cell bodies of postganglionic neurons. The axons of these neurons are short and end by supplying smooth muscle or glands of the viscera concerned.
- The other group of parasympathetic preganglionic neurons is located in the general visceral efferent nuclei of cranial nerves. The axons of these neurons terminate in autonomic ganglia associated with the third, seventh, ninth, and tenth cranial nerves. The postganglionic neurons are situated in these ganglia. They supply smooth muscle or glands.

Afferent Neurons

Afferent nerve fibres can be divided into four categories, *viz.* general somatic afferent, special somatic afferent, general visceral afferent, and special visceral afferent. The basic arrangement of the neurons that give origin to all four categories of afferent fibres is similar and the description that follows applies to all of them.

The cell bodies of neurons that give rise to efferent fibres of peripheral nerves are located within the brain and spinal cord. In contrast, the cell bodies of neurons that give rise to afferent fibres are located outside the CNS. In the case of spinal nerves, the cell bodies lie in the spinal ganglia and in the case of the cranial nerves, they lie in sensory ganglia, (e.g. the trigeminal ganglion) associated with these nerves. The arrangement of an afferent neuron with reference to a spinal nerve is illustrated in Figure 1.16.

The cells of the dorsal nerve root ganglion are of the unipolar variety. Each cell gives off a single process that divides into a peripheral process and a central process. The peripheral process extends into the spinal nerve and courses through its branches to reach the tissue or organ supplied. It may branch repeatedly during its course. These peripheral processes are functionally dendrites, as they convey impulses towards the cell body, but they are indistinguishable in structure from axons. These processes constitute the sensory fibres of peripheral nerves. The sensory impulses brought by these processes from various organs of the body are conveyed to the spinal cord by the central processes (representing axons). Within the spinal cord, the central processes usually run a short course and terminate by synapsing with cells in the posterior grey column. Some of the central processes are, however, long. They enter the posterior funiculus and run upwards to the medulla as ascending tracts.

The sensory ganglia of the fifth, seventh, ninth, and tenth cranial nerves are made up of cells similar to those of the spinal ganglia. Their central processes end by synapsing with cells in the sensory nuclei of these nerves. The sensory ganglia of the eighth nerve (i.e. the cochlear and vestibular ganglia) are peculiar, in that their neurons are bipolar, the two processes corresponding to the central and peripheral processes of unipolar neurons. They subserve special somatic afferent function.

Arrangement of Neurons within the Central Nervous System

The arrangement of neurons considered so far are of two types:

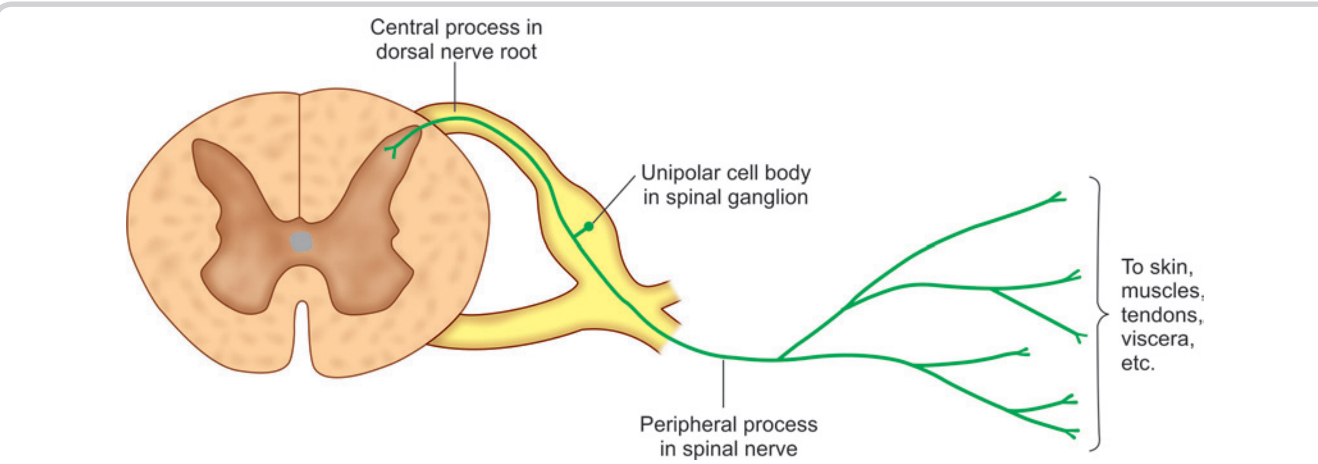


Figure 1.16: Scheme to show the typical arrangement of an afferent neuron

- Having cell bodies that lie within the brain and spinal cord and sending out efferent processes that leave the CNS to form the motor fibres of peripheral nerves.
- Having cell bodies located in ganglia outside the CNS but sending processes into it.

The bulk of the CNS is, however, made up of neurons that lie entirely within it. As explained earlier, the cell bodies of these neurons are invariably located in masses of grey matter. The axons may be short, ending in close relation to the cell body (***short axon neurons*** or ***Golgi type II neurons)***, or may be long (***long axon neurons*** or ***Golgi type I neurons)*** and may travel to other masses of grey matter lying at considerable distances from the grey matter of origin. The neurons within the CNS are interconnected in an extremely intricate manner. The basic arrangement encountered can be understood by understanding of reflexes and their mechanism.

Reflex Action and Types of Reflexes

A reflex action is defined as an immediate, involuntary motor response of the muscles in response to a specific sensory stimulus. For example, if the skin of the sole of a sleeping person is scratched, the leg is reflexly drawn up.

The simplest possible arrangement and the mechanism of reflex are shown in Figure 1.17. The stimulus applied to the skin gives rise to a nerve impulse, which is carried by the peripheral process of a unipolar neuron to the spinal ganglion. From here, the impulse passes into the central process, which terminates by directly synapsing with an anterior horn cell supplying the muscle which draws the leg up. The complete pathway constitutes a ***reflex arc,*** and in the above example, it consists of two neurons—one afferent and the other efferent. As only one synapse is involved, the reflex is ***monosynaptic***.

In actual practice, however, the reflex arc is generally made up of three neurons as shown in Figure 1.18. The central process of the dorsal nerve root ganglion cell ends by synapsing with a neuron lying in the posterior grey column. This neuron has a short axon that ends by synapsing with an anterior horn cell, thus completing the reflex arc. The third neuron interposed between the afferent and efferent neurons is called an ***internuncial neuron*** or simply an ***interneuron***. For obvious reasons, such a reflex is said to be ***polysynaptic***. It is important to know that various tendon reflexes are dependent on monosynaptic reflex arcs.

The purpose served by an interneuron may be basically of three types. Firstly, the axon arising from an interneuron may be divided into a number of branches and may synapse with a number of efferent neurons (Figure 1.19A). As a result, an impulse coming along a single afferent neuron may result in an effector response by a large number of efferent neurons. Secondly, afferent impulses brought by a number of afferent neurons may converge on a single efferent neuron through the agency of interneurons (Figure 1.19B). Some of these impulses tend to induce activity in the efferent neuron (i.e., they are ***facilitatory),*** while others tend to suppress activity (i.e., they are ***inhibitory***). Thirdly, through interneurons, an afferent neuron may establish contact with efferent neurons in the opposite half of the spinal cord or in a higher or lower segment of the cord.

Some reflexes are protective, e.g. withdrawal of the hand when a hot object is touched. In such a movement involving withdrawal, joints of the extremity are flexed. Such reflexes are, therefore, also called ***flexor reflexes.*** When a person is standing, a series of reflexes are active to prevent him from falling. As these keep the body straight (with the hip and knee joints extended), they are called ***extensor reflexes***

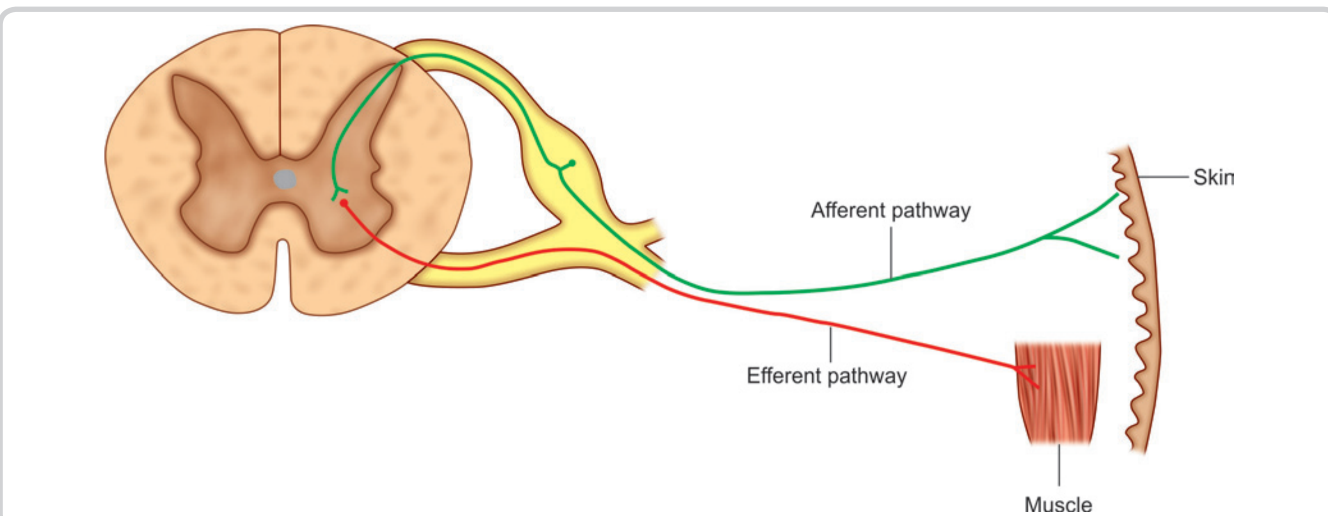


Figure 1.17: A monosynaptic spinal reflex arc composed of two neurons

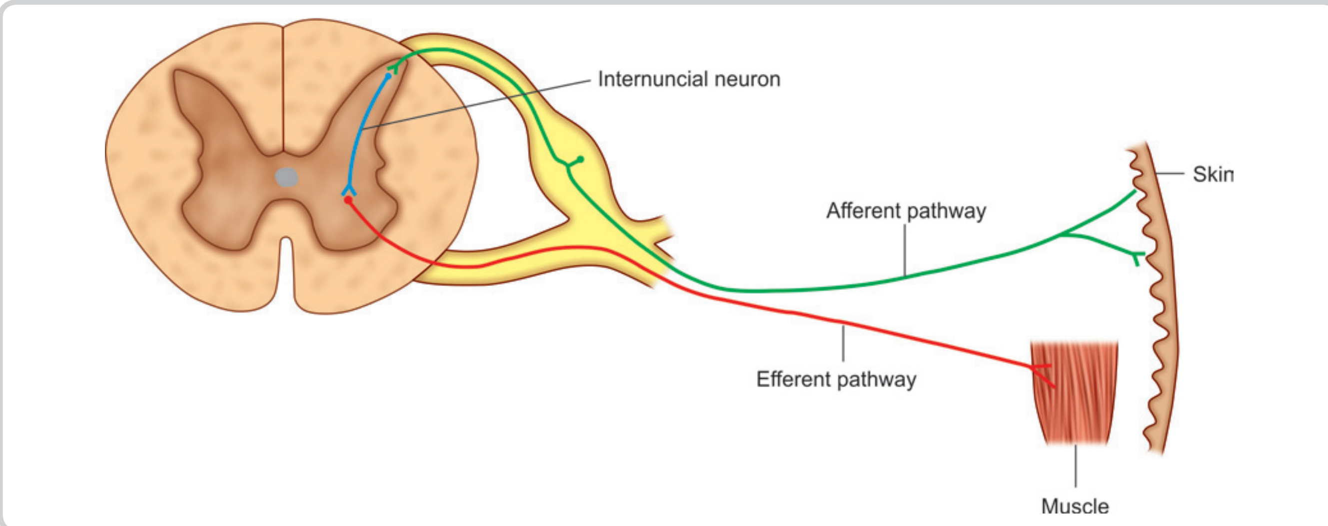
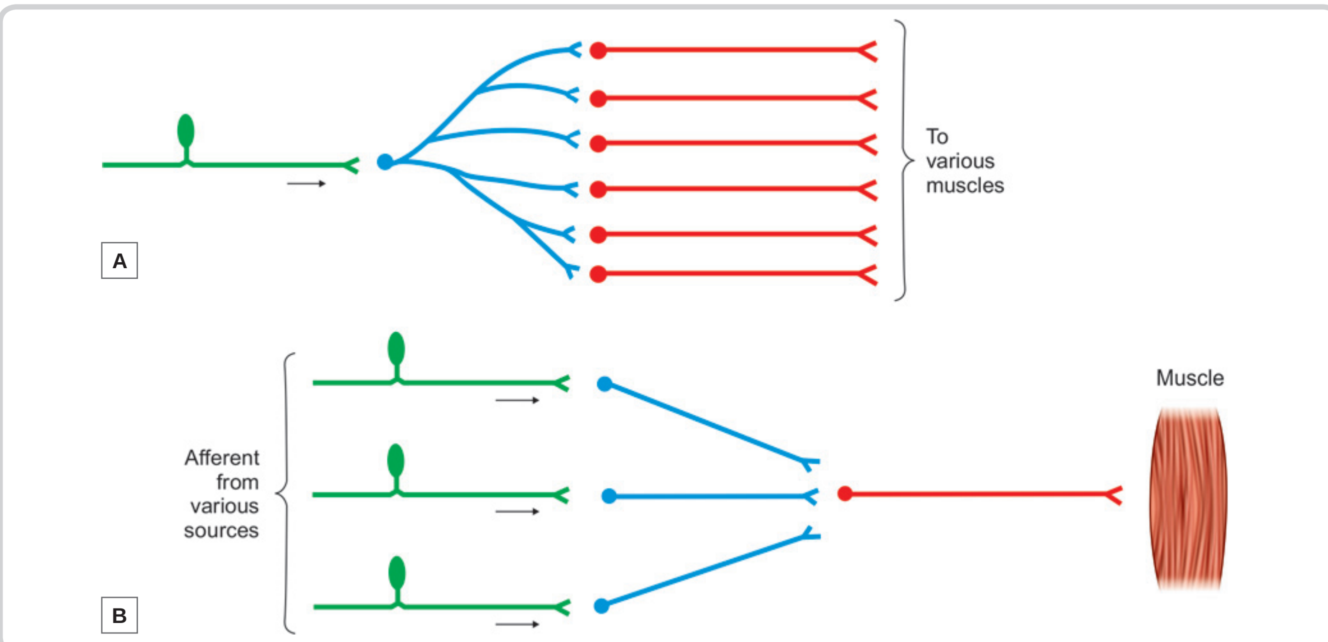


Figure 1.18: A polysynaptic spinal reflex arc composed of three neurons



Figures 1.19A and B: Schemes to illustrate two roles which internuncial neurons may play—the internuncial neurons are shown in blue lines

or ***antigravity reflexes***. Maintenance of posture through such reflexes is influenced by the membranous labyrinth, the cerebellum, and other centres in the brain. Vision is also important in maintaining correct posture.

Every time a stimulus reaches a neuron, it does not mean that it must become active and must produce an impulse. A neuron receives inputs from many neurons (in some cases, from hundreds of them). Some of these inputs are facilitatory and others are inhibitory. Activity in the neuron (in the form of initiation of an impulse) depends on the sum total of these inputs. Thus, each neuron may be regarded as a decision-making centre. The greater the number of neurons involved in any pathway, the greater the possibility of such interactions. Viewed in this light, it will become clear that interneurons interposed in a pathway increase the number of levels at which 'decisions' can be taken. It will also be appreciated that most of the neurons within the nervous system are, in this sense, interneurons, which are involved in numerous highly complex interactions on which the working of the nervous system depends.

From what has been said above, it will be seen that some activities occur due to reflex action and may involve only neurons within the spinal cord. However, most activities of the spinal cord are subjected to influence from higher centres. In the more complicated types of activity, several higher centres may be involved and the pathways may be

extremely complicated. Afferent impulses reaching these higher centres (e.g. the cerebral cortex) would appear to be somehow stored and this stored information (of which one may or may not be conscious) is used to guide responses to similar stimuli received in future. This accounts for memory and for learning processes.

DEGENERATION AND REGENERATION OF NEURONS

When the axon of a neuron is crushed or cut across, a series of degenerative changes are seen in the axon distal to the injury, in the axon proximal to the injury, and in the cell body.

Anterograde Degeneration

The changes in the part of the axon distal to the injury are referred to as ***anterograde degeneration*** or ***Wallerian degeneration***. They take place in the entire length of this part of the axon (Figure 1.20).

- A few hours after injury the axon becomes swollen and irregular in shape, and in a few days, it breaks up into small fragments.
- The neurofibrils within it break down into granules.
- The myelin sheath breaks up into small segments. It also undergoes chemical changes that enable degenerating myelin to be stained selectively.
- The region is invaded by numerous macrophages that remove degenerating axons, myelin, and cellular debris. These macrophages probably secrete substances that cause proliferation of Schwann cells and also produce nerve growth factors.
- The Schwann cells increase in size and produce a large series of membranes that help form numerous tubes. These tubes play a vital role in regeneration of nerve fibres.

Retrograde Degeneration

Degenerative changes in the neuron proximal to the injury are referred to as ***retrograde degeneration***. These changes take place in the cell body and in the axon proximal to injury.

Degenerative Changes Inside the Cell Body

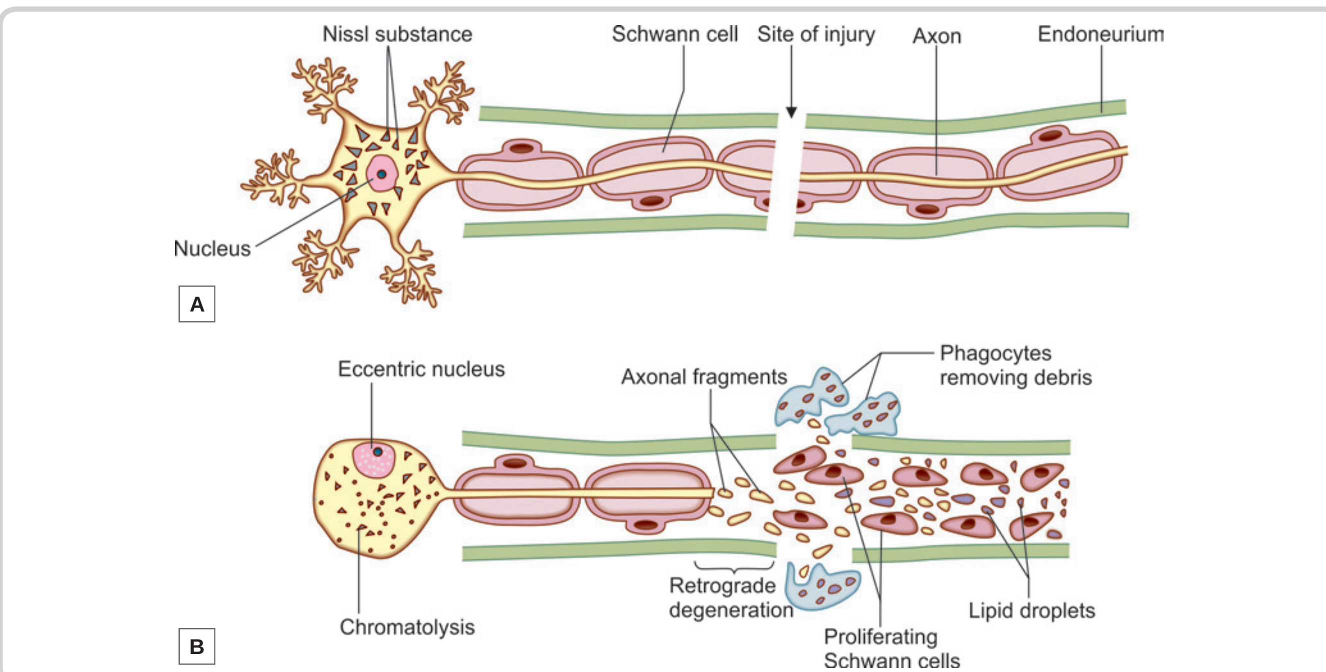
The cell body of the injured neuron undergoes a series of changes that constitute the phenomenon of ***chromatolysis***.

The cell body enlarges tending to become spherical. The nucleus moves from the centre to the periphery. The Nissl substance becomes much less prominent and appears to dissolve away; hence, the term chromatolysis.

Ultrastructural and histochemical alterations occur in the cell body. The severity of the reaction shown by the cell body is variable. In some cases, chromatolysis ends in cell death, followed by degeneration of all its processes. The reaction is more severe when the injury to the axon is near the cell body. If the cell survives, the changes described above are reversed after a period of time.

Degenerative Changes in the Promixal Axon

Changes in the proximal part of the axon are confined to a short segment near the site of injury (Figure 1.20). If the



Figures 1.20A and B: (**A**) Schematic diagram to show neuron soon after injury (**B**) Degenerative changes occuring after neuronal injury

injury is sharp and clean, the effects extend only up to one or two nodes of Ranvier proximal to the injury. If the injury is severe, a longer segment of the axon may be affected. The changes in the affected part are exactly the same as described for the distal part of the axon.

Transneuronal Degeneration

It is sometimes observed that changes resulting from axonal injury are not confined to the injured neuron but extend to other neurons with which the injured neuron synapses. This phenomenon is referred to as ***transneuronal degeneration***. The degeneration can extend through several synapses (as demonstrated in the visual pathway).

Regeneration of Nerve Fibres

The regeneration of axon is a slow process and may take months. It usually begins two weeks after injury.

Macrophages remove the debris from the site of injury and Schwann cells proliferate by mitotic division to fill the gap between the promixal and distal cut ends of the axon.

In the distal stump, the Schwann cell of neurilemma divides rapidly to form numerous tubes.

The promimal axon gives off a number of fine branches (sprouts). These branches grow into the connective tissue at the site of injury in an effort to reach the distal cut end of the nerve (Figure 1.21).

When one of the regenerating axonal branches succeeds in reaching such a tube, it enters it and then grows rapidly within it. The tube serves as a guide to the growing fibre.

Axonal branches that fail to reach one of the tubes degenerate.

It often happens that more than one axonal branch enter the same tube. In that case, the largest branch survives and the others degenerate.

The axon terminal growing through the Schwann cell tube ultimately reaches and establishes contact with an appropriate peripheral end organ. Failure to do so results in degeneration of the newly formed axon.

The new axon formed in this way is at first very thin and devoid of a myelin sheath. However, there is progressive increase in its thickness, and a myelin sheath is formed around it by the Schwann cell.

From the above account, it will be clear that chances of regeneration of a cut nerve are considerably increased, if the two cut ends are near each other and, if scar tissue does not intervene between them. It has been observed that tubes formed by Schwann cells begin to disappear, if they are not invaded by axons for a long time.

Axons in the CNS do not regenerate as in peripheral nerves. However, it has been seen that if a peripheral nerve is implanted into the CNS, axons tend to grow into the nerve. This may provide a method by which regeneration of tracts could be achieved within the CNS. It appears probable that implanted peripheral nerves provide the necessary environment for regeneration of axons (which the CNS is itself unable to provide).

Factors Necessary for Satisfactory Regeneration

Chances of regeneration of a damaged nerve are better under the following conditions:

- The nerve is crushed, but there is no separation of the two ends. The endoneural sheath should be intact
- Separation of cut ends should be minimal. Scar tissue should not intervene between the two ends
- Infection should not be present.

Clinical Correlation

- Sometimes during regeneration of a mixed nerve, axons may establish contact with the wrong end organs. For example, fibres that should reach a gland may reach the skin. When this happens in the auriculotemporal nerve, it gives rise to ***Frey's syndrome***. Instead of salivation there is increased perspiration, increased blood flow, and pain over skin.
- If the gap between the two cut ends is more, the growing axonal buds get mixed up with connective tissue to form a mass called a ***neuroma.***
- Apart from injury, neurons may be affected by degeneration. Loss, by degeneration, of myelin sheaths can give

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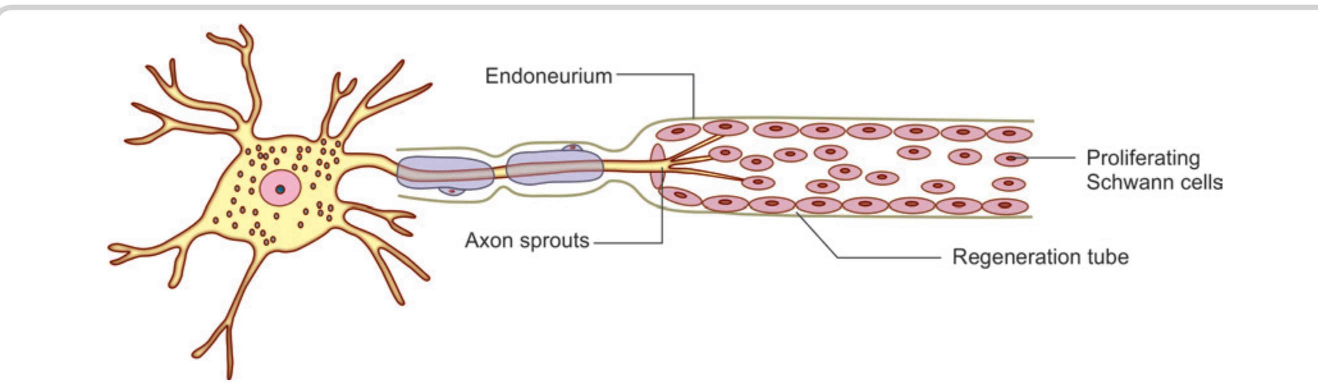


Figure 1.21: Schematic diagram to show neuronal regeneration after injury

rise to several conditions, the most important of which is ***multiple sclerosis***. The condition is confined to the CNS, and peripheral nerves are spared. Symptoms include weakness and various sensory disturbances. Multiple sclerosis is believed to be an autoimmune disease.

- Prolonged pressure on a nerve can cause temporary loss of function. This can occur in unconsciousness or even in deep sleep and in bedridden patients. Pressure on the radial nerve can cause the condition known as ***Saturday night palsy***. Pressure on blood vessels supplying a nerve can lead to a painful condition called ***ischemic neuritis***.

NEUROGLIA

In addition to neurons, the nervous system contains several types of supporting cells called neuroglia (Figure 1.22).

Types of Neuroglia

- Astrocytes, oligodendrocytes, and microglia found in the parenchyma of the brain and spinal cord.
- Ependymal cells, lining the ventricular system.
- Schwann cells, lemmocytes or peripheral glia forming myelin sheaths around axons of peripheral nerves. It is important to note that both neurilemma and myelin sheaths are components of Schwann cells.
- Capsular cells (also called satellite cells or capsular gliocytes) that surround neurons in peripheral ganglia.
- Various types of supporting cells found in relation to motor and sensory terminals of nerve fibres.

Some workers use the term neuroglia for all these categories, while others restrict the term only to supporting cells present within the brain and spinal cord. The latter convention is used in the description that follows.

Neuroglia of Brain and Spinal Cord

Neuroglial cells present in the parenchyma of brain and spinal cord are mainly of four types:

- Astrocytes, that may be subdivided into fibrous and protoplasmic astrocytes
- Oligodendrocytes
- Ependymal cells
- Microglia.

All neuroglial cells are much smaller in size than neurons. However, they are far more numerous. It is interesting to note that the number of glial cells in the brain and spinal cord is 10–50 times as much as that of neurons. Neurons and neuroglia are separated by a very narrow extracellular space.

In ordinary histological preparations, only the nuclei of neuroglial cells are seen. Their processes can be demonstrated by special techniques.

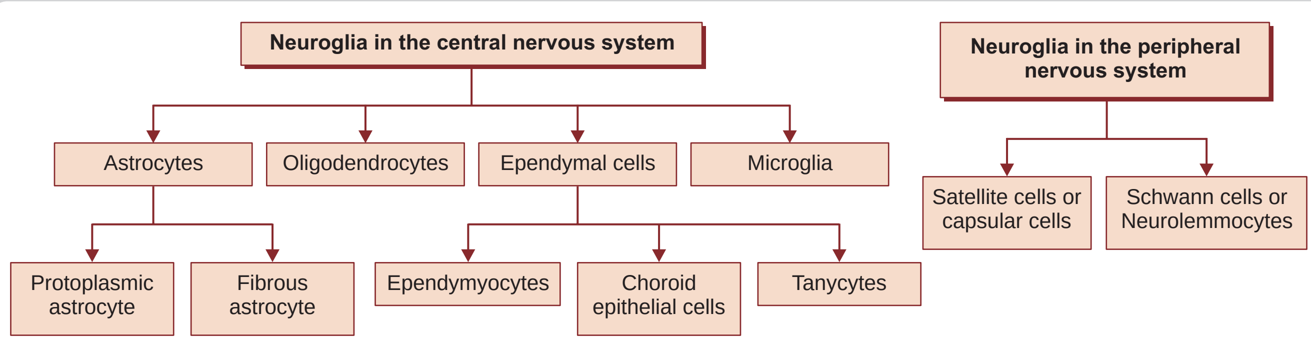
Astrocytes

These are small star-shaped cells that give off a number of processes (Figure 1.23). The processes are often flattened into leaf-like laminae that may partly surround neurons and separate them from other neurons. The processes frequently end in expansions in relation to blood vessels or in relation to the surface of the brain. Small swellings called ***gliosomes*** are present on the processes of astrocytes. These swellings are rich in mitochondria.

Astrocytes are of two types—fibrous and protoplasmic.

- ***Fibrous astrocytes*** are seen mainly in the white matter. Their processes are thin and are asymmetrical.
- ***Protoplasmic astrocytes*** are seen mainly in grey matter. Their processes are thicker than those of fibrous astrocytes and are symmetrical.
- ***Intermediate forms*** between fibrous and protoplasmic astrocytes are also present.

The processes of astrocytes are united to those of other astrocytes through gap junctions. Astrocytes communicate with one another through calcium channels. Such communication plays a role in regulation of synaptic



Note:
- Astrocytes and oligodendrocytes are together called as macroglia.
- Macroglia cells are derived from ectoderm of neural tube. Microglia cells are of mesodermal origin.
- Schwann cells and satellite cells are derived from neural crest

Figure 1.22: Types of neuroglia found in central and peripheral nervous systems

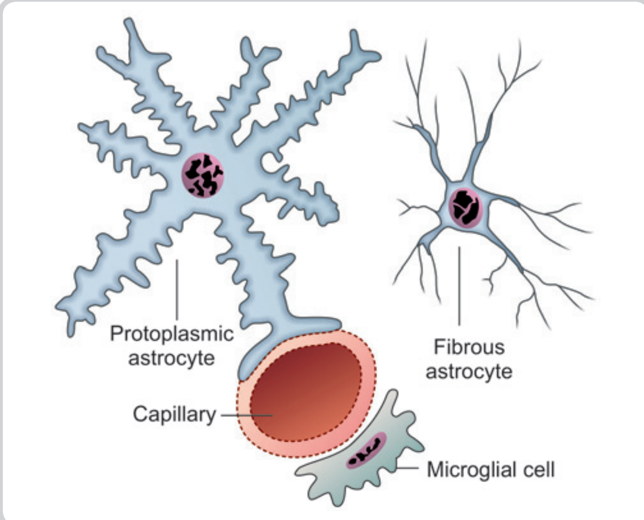


Figure 1.23: Astrocytes and macroglial cells. Note the peri-vascular feet of astrocytes forming a sleeve around a capillary

activity and in the metabolism of neurotransmitters and neuromodulators.

Functions

- They provide mechanical support to neurons.
- In view of their nonconducting nature, they serve as insulators and prevent neuronal impulses from spreading in unwanted directions.
- They are believed to help in neuronal function by playing an important role in maintaining a suitable metabolic environment for the neurons. They can absorb neurotransmitters from synapses, thus, terminating their action.
- They help in the formation of blood–brain barrier.
- Substances secreted by end feet of astrocytes probably assist in maintaining a membrane, the ***glia limitans externa***, which covers the exposed surfaces of the brain. They also help to maintain the basal laminae of blood vessels that they come in contact with.
- Astroglial cells are also responsible for repair of damaged areas of nervous tissue. They proliferate in such regions (**gliosis**). The microglia act as macrophages to engulf and destroy unwanted material.

Oligodendrocytes

These cells are rounded or pear-shaped bodies with relatively few processes (oligo—scanty) (Figure 1.24).

These cells provide myelin sheaths to nerve fibres that lie within the brain and spinal cord. Their relationship to nerve fibres is basically similar to that of Schwann cells to peripheral nerve fibres. However, in contrast to a Schwann cell that ensheaths only one axon, an oligodendrocyte may enclose several axons.

Oligodendrocytes are classified into several types depending on the number of neurons they provide sheaths

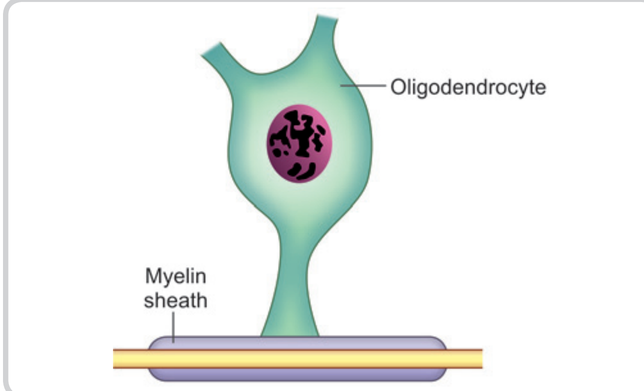


Figure 1.24: Oligodendrocyte and its relationship to a neuron

to. As a rule, oligodendrocytes present in relation to large diameter axons provide sheaths to fewer axons than those related to axons of small diameter. The plasma membrane of oligodendrocytes comes into contact with axolemma at nodes of Ranvier.

Function

Oligodendrocytes provide myelin sheaths to nerve fibres within the CNS for fast conduction of nerve impulses.

Ependymal cells

Ependymal cells line the ventricles of the brain and central canal of the spinal cord. Ependymal cells are mainly of three types:

- Ependymocytes
- Choroid epithelial cells
- Tanycytes

The ependymocytes constitute the majority of the ependymal cells. The specialized ependymal cells in choroid plexuses (choroidal epithelial cells) secrete cerebrospinal fluid. The ependymal cells lining the floor of the fourth ventricle have long basal processes and are termed "***tanycytes***".

Functions

Ependymal cells are concerned in exchanges of material between the brain and the cerebrospinal fluid at the brain-cerebrospinal fluid barrier. The blood in the capillaries of the choroid plexus is filtered through choroid epithelial cells at the blood–cerebrospinal fluid barrier to secrete cerebrospinal fluid.

Microglia

These are the smallest neuroglial cells (Figure 1.23). The cell body is flattened. The processes are short. These cells are frequently seen in relation to capillaries. As already stated, they differ from other neuroglial elements in being mesodermal in origin. They are probably derived from monocytes that invade the brain during fetal life. They are more numerous in the grey matter than in the white matter.

Function

They act as phagocytes and become active after damage to nervous tissue by trauma or disease. The microglia act as macrophages to engulf and destroy unwanted material.

NEUROBIOTAXIS

Origin: G. Neuro = nerve + bio = life + taxis = arrangement; literally, a law governing the arrangement of neuronal cell bodies and their fibres during life.

There are three components of this law. They are as follows:

- Neuronal cell body migrates towards the greatest density of stimuli.
- Neuronal cell body has a tendency for centralization, encephalization and telencephalization.
- Neuronal cell bodies with similar function group themselves together, and the processes with similar function run together in bundles.

Neuronal Cell Body Migrates towards the Greatest Density of Stimuli

The classical example for the first law is that of the nucleus and course of facial nerve in the brain stem. The motor nucleus of facial nerve lies in the floor of the fourth ventricle in the special visceral efferent column. As growth proceeds, the nucleus migrates at first dorsally, relative to the abducens nucleus, and then ventrally to reach its adult position. As it migrates, the axons of the nucleus elongate marking the course along which the motor nucleus of facial nerve has travelled. Facial nerve migrates dorsomedially to be in close proximity to medial longitudinal fasciculus because the latter affords a pathway for connecting fibres of facial nerve and hypoglossal nuclei to facilitate simultaneous movements of the lips and tongue in speech. Facial nerve then migrates ventrolaterally to be in close proximity to the nucleus of spinal tract of trigeminal ("the greatest density of stimuli") to establish a quick reflex response.

The nucleus ambiguus migrates ventrolaterally towards the reticular formation of medulla oblongata. This is another example of neurobiotaxis. Nucleus ambiguus supplies the striated muscles of pharynx and larynx. The general visceral afferent fibres from the mucosa of the above organs give collaterals to the reticular formation. The nucleus ambiguus migrates towards the reticular formation ("the greatest density of stimuli") to complete the reflex arc.

Neurons in the ventral horn of spinal cord show a specific arrangement of their cell bodies. Those that supply the trunk lie medially because they receive their greatest input from the ventral corticospinal tract in the anterior funiculus close to the medial part of ventral horn. Those neurons that supply the limbs lie laterally because they receive their greatest input from the lateral corticospinal tract.

Neuronal Cell Body has a tendency for Centralization, Encephalization and Telencephalization

The next law of neurobiotaxis states that every neuron has a tendency to centralize (to become a part of central nervous system). Those that are already centralized, tend to encephalize (to become a part of the brain). Those that are encephalized, tend to telencephalized. Telencephalization is an evolutionary process by which functions that were governed by lower centres (in lower animals) are progressively being controlled by the telencephalon (cerebrum). This process results in increased complexity of cognitive processes. Sensory neurons (located in the dorsal nerve root ganglion or sensory neurons of cranial nerves) are pulled to the periphery due to the source of stimulus. However their tendency to centralize pulls them towards the central nervous system. The most primitive sensory columns of spinal cord (fasciculus gracilis and cuneatus) terminate in the nuclei located in the medulla oblongata (the process of encephalization). Neurons located close to these neurons crossed the midline in the lower medulla and terminated in the opposite side of the spinal cord. These neurons are part of the pyramidal tract (the process of telencephalization). Pyramidal tracts still continue to cross in the lower medulla oblongata.

Neuronal Cell Bodies with Similar Function Group themselves together, and the Processes with Similar Function Run Together in Bundles

The basal lamina forming motor neurons are a group entirely anterior to the sulcus limitans. The alar lamina (sensory and integrative in function) forms another aggregation behind sulcus limitans. Some nuclei of alar lamina with dissimilar function migrate and form discrete group, for example, red nucleus, pontine nucleus, etc. However, those with similar function continue to stay close. The medial and dorsal accessory olivary nuclei lie close to inferior olivary nucleus, as all of them form climbing afferent fibres of cerebellum.

The preganglionic (connector) efferents of sympathetic nervous system are located in the lateral horn of the spinal cord just anterior to sulcus limitans. The visceral afferent neurons are also located there, just posterior to sulcus limitans. Similarly, the similarity in function of the anterior and lateral spinothalamic tracts has made them into a single, anterolateral spinothalamic tract.

In the brainstem, descending fibres form a bundle in the basal part and ascending fibres form a bundle in the tegmentum. The descending brainstem pathways that are facilitatory to flexor muscles of the body are grouped together in the lateral funiculus of the spinal cord (the corticospinal, the rubrospinal, the medullary reticulospinal). Those descending brainstem pathways

that are facilitatory to extensor muscles of the body are grouped together in the anterior funiculus of the spinal cord (the pontine reticulospinal, vestibulospinal, tectospinal).

NEURAL STEM CELLS

Nervous tissue within the central nervous system, till recently, used to be considered as post-mitotic i.e. neurons are incapable of regeneration. However, recent research has identified cells which are capable of forming new neurons as well as glial cells in the subventricular zone of lateral ventricle and in the hippocampal gyrus. These areas are known as adult neurogenic zone. These cells which are called neural stem cells are capable of self-renewal and show plasticity. They may help in neuronal regeneration within the brain when exposed to specific neurotrophic factors but this field is still under intense research.

Table 1.5 | Examples of disorders of Nervous system

Congenital	• Anencephaly • Encephalocele • Hydrocephalus • Spina bifida and myelocele
Traumatic	• Cerebral concussion (mild traumatic brain injury) • Cerebral contusion • Coup injury (occurs under the site of impact with an object) • Contre coup injury (occurs when a moving head hits a stationary object causing CSF rushing to the area of impact during the injury, forcing the brain back on to the other side of the skull) • Diffuse brain damage • Injuries to spinal cord
Inflammatory	• Meningitis • Encephalomyelitis
Neoplastic	**Space occupying lesion** • Neuroglioma • Meningioma • Secondary metastasis
Degenerative	• Huntington's chorea • Friedreich's ataxia • Parkinson's disease • Alzheimer's disease • Subacute combined degeneration of spinal cord • Motor neuron disease (Amyotrophic lateral sclerosis) • Multiple sclerosis • Epilepsy • Migraine • Cerebral palsy
Vascular (intracranial bleed)	• Extradural haematoma (meningeal artery) • Subdural haematoma (dural venous sinus) • Subarachnoid haemorrhage (ruptured microaneurysm) • Intracerebral haemorrhage / thrombotic / embolic syndromes
Functional	• Schizophrenia • Mood disorder • Neurotic disorder • Personality disorder • Mental retardation • Disorders of psychological development
Peripheral nervous system	• Neuralgia • Nerve root and plexus disorders • Mononeuropathies • Polyneuropathies • Myasthenia gravis • Cauda equina syndrome • Disorders of autonomic nervous system

Clinical Correlation

Knowledge of anatomy is an essential prerequisite for the practice of any clinical discipline, but nowhere is this truer than in the diagnosis of neurological disorders (Table 1.5). The localisation of the *areas* of the nervous system *involved in disease* (***lesion***) calls for a fairly thorough knowledge of the location of various masses of grey matter, and of the courses of various tracts. The purpose of this chapter is to provide some illustrations of how knowledge of neuroanatomy can be of help in neurological diagnosis; and to introduce some terms that are commonly used in clinical practice.

In recent years, considerable advances in neurological diagnosis have become possible by the use of sophisticated imaging techniques like computed tomography (CT), and magnetic resonance imaging (MRI). In interpreting these images a thorough knowledge of the gross anatomy of the head, neck and brain (or of other regions concerned) is invaluable.

Damage to nervous tissue can occur due to various causes as listed below:

- **Traumatic**: Any part of the brain or spinal cord may be damaged by direct injury i.e. trauma. Apart from other obvious causes such injury may occur during child birth.
- **Vascular**: If nervous tissue is deprived of blood, even for a short period, irreversible damage may result. Localised damage of this kind may occur if one of the arteries supplying the brain is blocked. This may occur by clotting of blood within the vessel (***thrombosis***). Such an event is more likely in older individuals in whom the arteries have undergone a degenerative change known as ***arteriosclerosis*****.** A vessel can also be blocked by some extraneous material (e.g., clot, fat, air) reaching it from some other part of the body through the circulation. Such matter is called an ***embolus*****.** Sometimes an artery may rupture, the blood leaking into brain tissue i.e. ***haemorrhage*** causing considerable damage. A haemorrhage in the brain is often fatal. Bleeding may be caused by rupture of small abnormal dilatations of arteries (***aneurysms***). Aneurysms may be congenital, or may be produced due to weakening of the arterial wall in the region.
- **Neoplastic:** Another cause of brain damage is the presence of any abnormal mass within the cranial cavity. As the cranial cavity cannot expand, such a mass inevitably presses on brain tissue. A **space occupying lesion (SOL)** may be a tumour, a collection of pus, a collection of blood (in the epidural space) etc.] Apart from producing general signs of increased intracranial tension, local effects are produced depending on the area involved. Tumours of nervous tissue may be ***medulloblastomas*** or ***astrocytomas*** or ***oligodendromas.***
- **Infective:** Nervous tissue may be affected by infections, both acute and chronic. An infection in the brain is referred to as ***encephalitis***; and that in the spinal cord is called ***myelitis*****.**
- **Congenital malformations:** Defects in neural tissue may also be caused by ***maldevelopment*** (congenital anomalies).
- **Degenerative:** May be due to old age or due to various ***metabolic disorders*****.** Loss, by degeneration, of myelin sheaths can give rise to several conditions, the most important of which is ***multiple sclerosis***.
- **Functional:** Finally, alterations in nervous function may occur in the absence of recognisable structural changes. These are called ***functional disorders*****.**

Multiple Choice Questions

1. The 'Nissl substance' represents which organelle of neuron
   A. Golgi complex
   B. Nucleolus
   C. Rough endoplasmic reticulum
   D. Mitochondria
2. Bouton terminaux refers to which part of neuron
   A. Axon hillock
   B. Dendritic spine
   C. Internodal region
   D. Swelling at the end of axon
3. Which of the following provides myelin sheath to the axons of the CNS?
   A. Astrocytes
   B. Oligodendrocytes
   C. Microglia
   D. Ependymocytes
4. The neurons of the sympathetic ganglia are
   A. Multipolar
   B. Bipolar
   C. Unipolar
   D. Pseudounipolar
5. Which of the following cells functions as the macrophage of the CNS?
   A. Tanycyte
   B. Microglia
   C. Oligodendrocyte
   D. Ependymocyte
6. Which of the following is involved in 'replacement gliosis' following death of neurons?
   A. Astrocyte
   B. Oligodendrocyte
   C. Microglia
   D. Ependymocyte

7. The perivascular foot of the 'blood–brain barrier' is an extension from the
   A. Oligodendrocyte
   B. Ependymocyte
   C. Protoplasmic astrocyte
   D. Microglia
8. Which of the following is derived from the mesoderm?
   A. Oligodendrocyte
   B. Astrocyte
   C. Ependymal cell
   D. Microglia
9. Which of the following should be intact for the regeneration of an injured peripheral nerve to occur?
   A. Schwann cells
   B. Myelin sheath
   C. Neurilemma
   D. Perineurium
10. Most of the primary brain tumours arise from the following EXCEPT
    A. Neurons
    B. Neuroglia
    C. Meninges
    D. Blood vessels

Answers

1. C **2.** D **3.** B **4.** A **5.** B **6.** A **7.** C **8.** D **9.** C **10.** A

Chapter 2

Neuronal Contacts

Specific Learning Objectives

At the end of learning, the student shall be able to:
- Define and classify synapses
- Define and classify neuromuscular junctions
- Define and classify various sensory receptors
- Explain the anatomical basis of clinical conditions involving the neuromuscular junctions

Neurons make connections with other neurons within the central nervous system (CNS) or outside the CNS. Neurons also make connections with effector organs like muscles and glands and with the ***sensory receptors*** in the periphery. Sites of junction between neurons are called as ***synapses***. Sites of junction between neurons and muscles are called as ***neuromuscular junctions***.

SYNAPSES

A synapse transmits an impulse only in one direction. The two elements taking part in a synapse can, therefore, be spoken of as ***presynaptic*** and ***postsynaptic*** (Figure 2.1). In an axo-dendritic synapse, the terminal enlargement of the axon may be referred to as the ***presynaptic bouton*** or ***synaptic bag***. The region of the dendrite receiving the axon terminal is the ***postsynaptic process***. The two are separated by a space called the ***synaptic cleft***. Delicate fibres or granular material may be seen within the cleft. On either side of the cleft there is a region of dense cytoplasm. On the presynaptic side, this dense cytoplasm is broken up into several bits. On the postsynaptic side the dense cytoplasm is continuous and is associated with a meshwork of filaments called the ***synaptic web***.

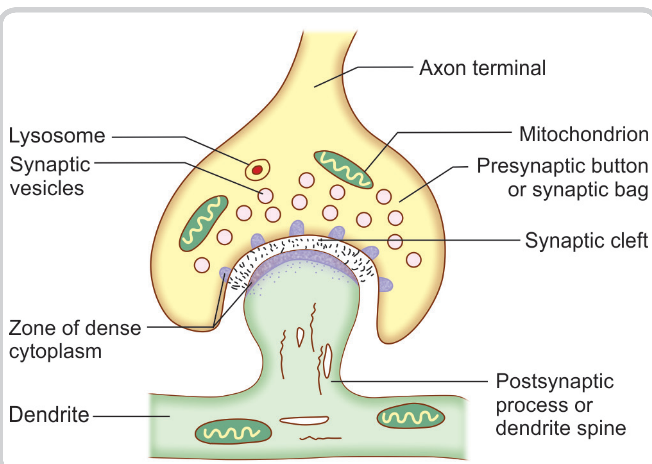


Figure 2.1: Scheme showing the structure of a typical synapse as seen by Electron Microscope

The axon may terminate in a single bulb-like end called a ***bouton*** (or ***synaptic bag***) or the terminal part of the axon may bear a number of such enlargements each of which synapses with the receiving neuron. Similarly dendrites may bear numerous spines. Axon terminals may synapse either with the dendritic spines or with the smooth portions of the dendrite between the spines. Occasionally, an axon terminal may end by synapsing with the terminal bouton of another axon forming what is called a ***serial synapse***. In some areas several neurons may take part in forming complex synapses encapsulated by neuroglial cells to form ***synaptic glomeruli*** (Figure 2.2). Such glomeruli are found in the cerebellum, the olfactory bulb and the lateral geniculate body.

At some sites several synapses may be present around a short length of a dendrite and may be enclosed within a glial capsule. Such a complex is called a ***synaptic cartridge***.

The thickened areas of membrane on the presynaptic and postsynaptic sides constitute the ***active zone*** of a synapse. Neurotransmission takes place through this region. Some variations in the structure of the active zone are described below.

Within the presynaptic bouton numerous synaptic vesicles can be seen. Mitochondria and lysosomes may also be present. The presynaptic bouton contains numerous microtubules (that extend into it from the axon). The tubules end near the presynaptic membrane. Synaptic vesicles are attached to the microtubules by short stalks. The postsynaptic process may also show membranous structures of various shapes, microtubules, filaments and endoplasmic reticulum.

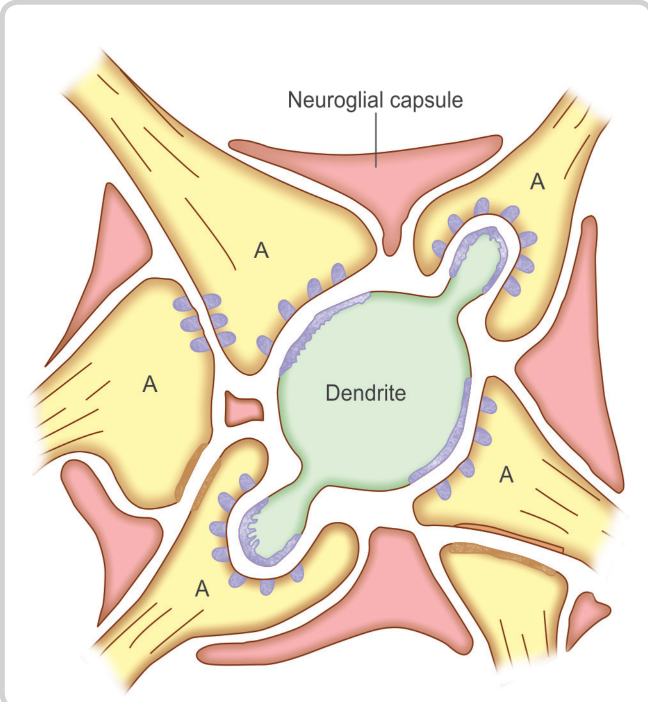


Figure 2.2: Diagram to show a synaptic glomerulus

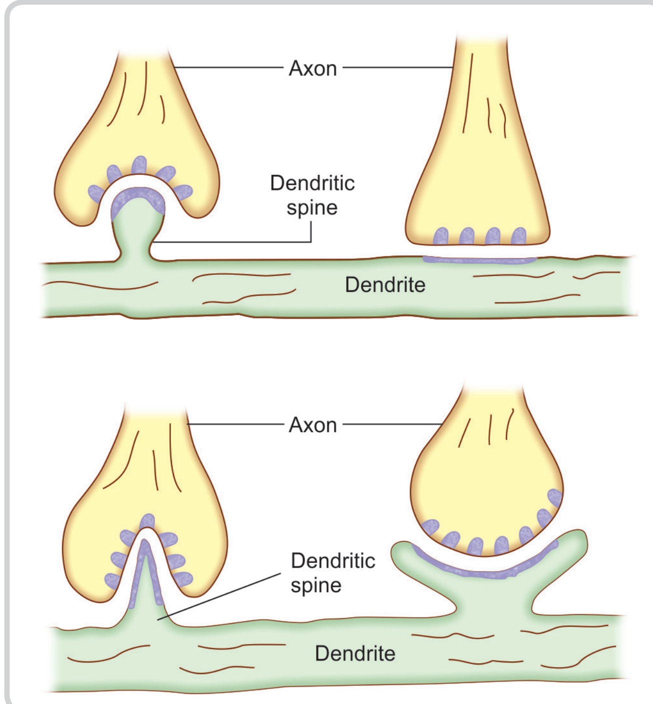


Figure 2.3: Variations in the orientation of axodendritic synapses

Various proteins and enzymes are present in relation to presynaptic and postsynaptic regions. Some of them (F-actin, spectrin) form a filamentous network that immobilises vesicles until they are to be released.

CLASSIFICATION OF SYNAPSES

I. ***Morphological classification:*** Synapses may be of various types depending on the neuronal elements taking part.

II. ***Ultrastructure classification:*** Synapses may also be classified on the basis of their ultrastructure and on the basis of the neurotransmitters released by them. Synapses in different situations can vary considerably in overall shape (Figure 2.3), in the size, shape and nature of synaptic vesicles and in the configuration of the presynaptic and postsynaptic areas of dense cytoplasm.

III. ***Functional classification:*** From a physiological viewpoint, a synapse may be ***excitatory or inhibitory.***

Morphological Types of Synapses

Synapses may be of various types depending upon the parts of the neurons that come in contact. In the most common type of synapse, an axon terminal establishes contact with the dendrite of a receiving neuron to form an ***axodendritic synapse*** (Figure 2.4). Synapses on dendrites may be located on spines or on the smooth areas between spines. The axon terminal may synapse with the cell body (***axosomatic synapse***) or less commonly, with the axon of the receiving neuron (***axoaxonal synapse***). An axo-axonal synapse may be located either on the initial segment (of the receiving axon) or just proximal to an axon terminal.

In some parts of the brain (e.g., the thalamus), there are synapses in which the presynaptic element is a dendrite instead of an axon. Such synapses may be called ***dendro-axonic*** or ***dendrodendritic***. In yet others, the soma of a neuron may synapse with the soma of another neuron (***somatosomatic synapse***) or with a dendrite (***somato-dendritic synapse***).

Ultrastructural Types of Synapses

Two main types of synapses are recognised on the basis of their ultrastructure:

- ***Asymmetric or Type I synapses:*** In these synapses, the subsynaptic zone of dense cytoplasm is thicker on the presynaptic side. The synaptic cleft is about 30 nm. Such synapses are excitatory
- ***Symmetric or Type II synapses:*** In these synapses, the subsynaptic zone of dense cytoplasm is thin and is of similar thickness on both sides. The synaptic cleft measures about 20 nm.

Various synapses intermediate in structure between these two main types are also encountered.

The vesicles to be seen within synapses can also be of various types. Some vesicles are clear while others have dense cores. They may be pleomorphic (i.e. a mixture of

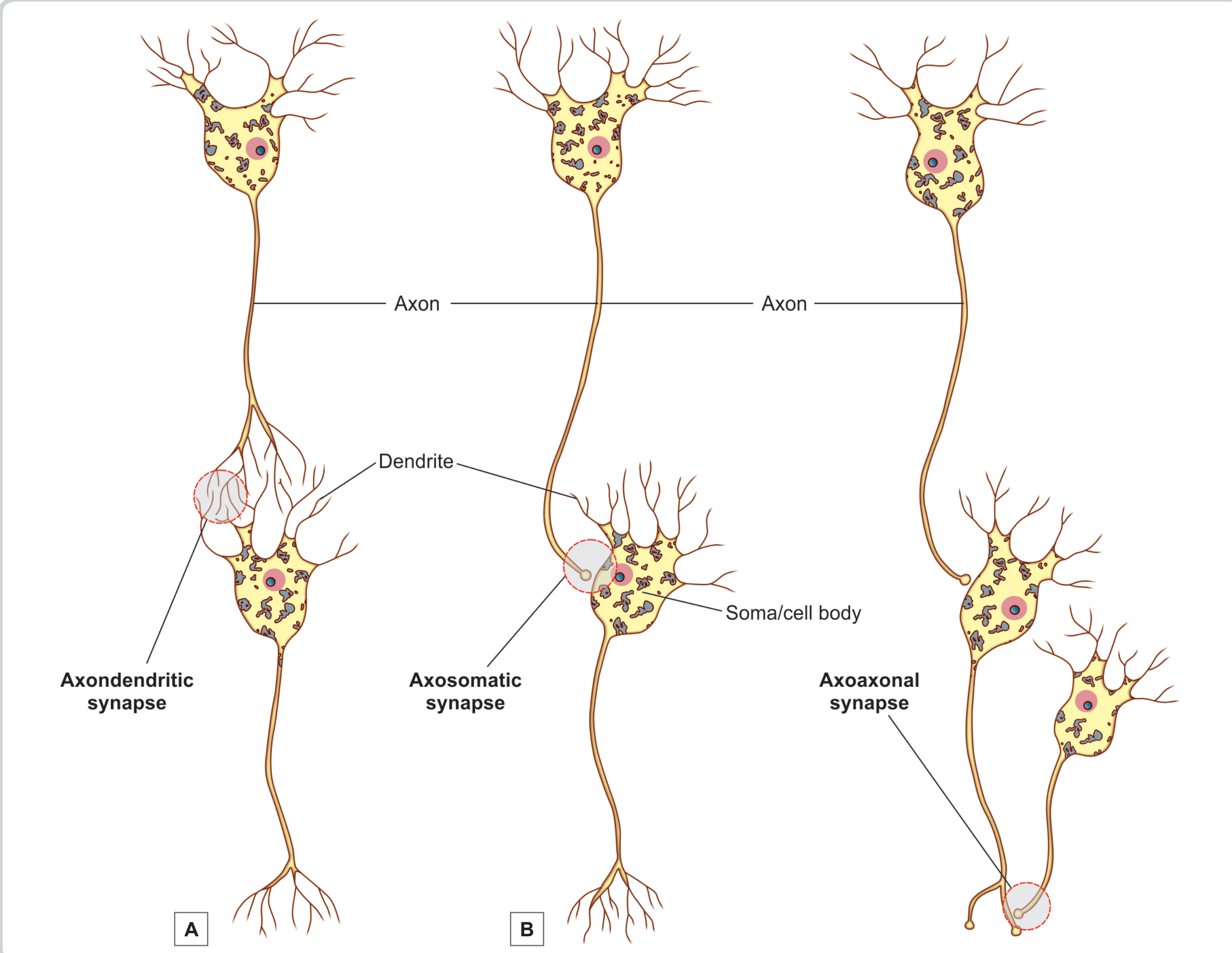


Figure 2.4: Various types of chemical synapses. (**A**) Axodendritic synapse; (**B**) Axosomatic synapse; (**C**) Axoaxonal synapse

various shapes). The appearance of vesicles can often be correlated with the neurotransmitter present. On the basis of these characters some sub-varieties of Type 1 and Type II synapses that have been recognised are given in Table 2.1.

In some synapses in the retina and internal ear, vesicles are arranged around a rod-like element placed at right angles to the cell membrane. This configuration is called a ***synaptic ribbon***. Within some dendritic spines collections of flattened cisternae (endoplasmic reticulum) with associated dense material are seen. These are given the name ***spine apparatus***.

Table 2.1 | Differences in the ultrastructure of synapses

Ultrastructural Type	Shape of vesicles	Neurotransmitter associated
Asymmetric	Small spherical	Acetylcholine Glutamine Serotonin
	Dense cored	Noradrenaline Adrenaline Dopamine
Symmetric	Pleomorphic	GABA and glycine

Abbreviation: GABA, gamma-aminobutyric acid

Electrical Synapses

Synapses involving the release of neurotransmitters are referred to as **chemical synapses**. At some sites one cell may excite another without the release of a transmitter. At such sites adjacent cells have direct channels of communication through which ions can pass from one cell to another altering their electrical status. Such synapses are called ***electrical synapses***.

At the site of an electrical synapse plasma membranes (of the two elements taking part) are closely applied, the gap between them being about 4 nm. Proteins called ***connexins*** project into this gap from the membrane on either side of the synapse. The proteins are so arranged that small open channels are created between the two synaptic elements.

Electrical synapses are common in lower vertebrates and invertebrates. They have been demonstrated at some sites in the brains of mammals (e.g., in the inferior olive and cerebellum).

Junctions between receptors and neurons or between neurons and effectors, share some of the features of typical synapses and may also be regarded as synapses. ***Junctions between cardiac myocytes and between smooth muscle cells*** *are regarded as* ***electrical synapses.***

Influence of Neural Activity on Synapses

It has been shown that neural activity stimulates the development of new synapses and causes increase in their size especially in early postnatal life. Some experiments show that even in later life, periods of brief synaptic stimulation can have an influence on the subsequent functioning of the synapse. This is especially true in areas like the hippocampus which are associated with memory.

NEUROTRANSMITTERS

The transmission of impulses through synapses involves the release of chemical substances called ***neurotransmitters*** that are present within synaptic vesicles. When a nerve impulse reaches a terminal bouton, neurotransmitter is released into the synaptic cleft. Under the influence of the neurotransmitter, the postsynaptic surface becomes depolarised resulting in a nerve impulse in the postsynaptic neuron. In the case of inhibitory synapses, the presence of the neurotransmitter causes hyperpolarisation of the postsynaptic membrane. The neurotransmitter released into the synaptic cleft acts only for a very short duration. It is either destroyed (by enzymes) or is withdrawn into the terminal bouton.

When an action potential reaches the presynaptic terminal, voltage sensitive calcium channels are opened up so that there is an influx of calcium ions leading to a series of chemical changes. As a result of these changes synaptic vesicles pour the neurotransmitter stored in them into the synaptic cleft. The neurotransmitter reaches and binds onto receptor molecules present in the postsynaptic membrane. This alters permeability of the postsynaptic membrane to ions of calcium, sodium, potassium or chloride leading to depolarisation (or hyperpolarisation at inhibitory synapses). The best known (or classical) neurotransmitters responsible for fast but short-lived action of the kind described above are acetylcholine, noradrenaline and adrenaline. For long, all nerve terminals were regarded as either ***cholinergic*** or ***adrenergic***, until it was recognised that these were not the only neurotransmitters present. Other fast neurotransmitters whose presence is now well established are dopamine and histamine.

It is also recognised that apart from the neurotransmitters mentioned above numerous other chemical substances are associated with synapses. Some of these, which probably act as neurotransmitters are serotonin, gamma-aminobutyric acid (GABA), glutamate, aspartate and glycine.

It is now known that at some synapses the effect of a neurotransmitter may last for seconds or even minutes. Repeated synaptic activity can have long lasting effects on the receptor neuron including structural changes such as the formation of new synapses, alterations in the dendritic tree, or growth of axons. Such effects produced under the influence of chemical substances are described as ***neuromediation;*** the chemical substances concerned being called ***neuromediators***. This term includes ***neurohormones***, synthesised in neurons and poured into the blood stream through terminals resembling synapses in structure. Similar chemical substances are also poured into the cerebrospinal fluid or into intercellular spaces to influence other neurons in a diffuse manner.

Lastly, some chemical substances associated with synapses do not influence synaptic transmission directly, but influence the effects of transmitters or of neuromediators. Such chemical substances are referred to as ***neuromodulators***. Several peptides found in the nervous system probably act as neuromodulators. These include substance P, vasoactive intestinal polypeptide (VIP), somatostatin, cholecystokinin and many others.

The following factors can influence synaptic transmission and thereby the speed of responses:

- Drugs like caffeine produce their stimulatory effect by stimulating synaptic transmission.
- Synaptic transmission may decrease in old age because calcium ion channels become fewer. In the case of the heart this may impair the stimulating effect of exercise on heart rate and cardiac output.
- Synaptic transmission is disturbed in some diseases like myasthenia gravis.
- It is also affected in poisoning by organophosphates. In this condition the action of acetylcholine esterase is inhibited and acetylcholine accumulates. This can lead to spasm of respiratory muscles and death.

Neurons also show considerable variation in the number and nature of synapses established by them.

NEUROMUSCULAR JUNCTIONS

Skeletal muscle fibres are supplied by ramifications of somatic efferent neurons and axonal branches arising from one neuron may innervate a variable number of muscle fibres that constitute a motor unit.

Each skeletal muscle fibre receives its own direct innervation. The site where the nerve ending comes into intimate contact with the muscle fibre is a neuromuscular

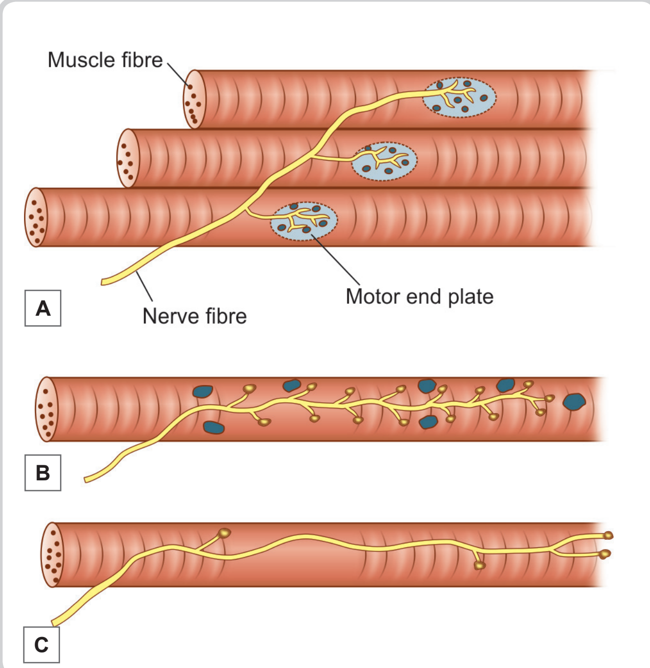


Figure 2.5: Various types of neuromuscular junctions. **(A)** En plaque endings; **(B)** En grappe ending; **(C)** Trail endings

(or myoneural) junction. Details of these junctions vary in different skeletal muscle fibres as follows.

- **Motor End Plates or 'En Plaque' Endings**
  In most neuromuscular junctions, the nerve terminal comes in contact with a specialised area near the middle of the muscle fibre. This area is roughly oval or circular, and is referred to as the ***sole plate***. The sole plate plus the axon terminal constitute the ***motor end plate***. Motor end plates are considered in detail below (Figure 2.5A).
- **'En Grappe' Endings**
  On reaching a muscle fibre, some axon terminals divide into a number of small ramifications, each ending in an expansion applied to the surface of the muscle fibre. These are referred to as "en grappe" endings (Figure 2.5B).
- **Trail Endings**
  In some cases the nerve fibre runs for some distance along the length of the muscle fibre giving off several ramifications that come in contact with the latter.
  "En grappe" and trail endings are seen mainly in relation to intrafusal muscle fibres present in muscle spindles (Figure 2.5C).

STRUCTURE OF A TYPICAL MOTOR END PLATE

In the region of the motor end plate axon terminals are lodged in grooves in the sarcolemma covering the sole plate (Figure 2.6). Between the axolemma (over the axon) and the sarcolemma (over the muscle fibre) there is a

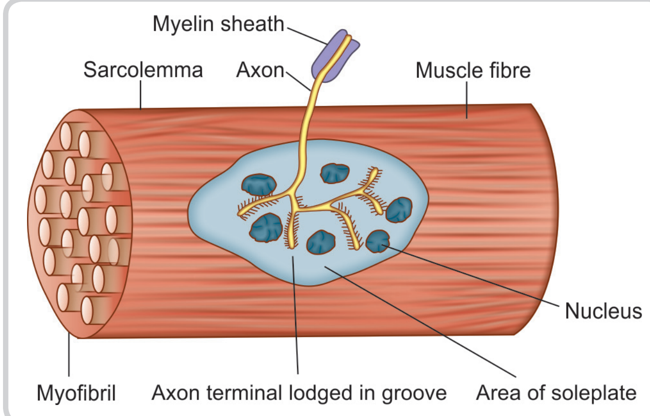


Figure 2.6: Motor end plate seen in relation to a skeletal muscle fibre (surface view)

narrow gap (about 40 nm) occupied by various proteins that form a basal lamina. It follows that there is no continuity between axoplasm and sarcoplasm.

Axon terminals are lodged in grooves in the sarcolemma covering the sole plate. In section (Figure 2.7) this groove is seen as a semicircular depression. This depression is the primary cleft. The sarcolemma in the floor of the primary cleft is thrown into numerous small folds resulting in the formation of secondary (or subneural) clefts.

In the region of the sole plate the sarcoplasm of the muscle fibre is granular. It contains a number of nuclei and is rich in mitochondria, endoplasmic reticulum and Golgi complexes.

Axon terminals are also rich in mitochondria. Each terminal contains vesicles similar to those seen in presynaptic boutons. The vesicles contain the neurotransmitter acetylcholine. Acetylcholine is released when nerve impulses reach the neuromuscular junction. It initiates a wave of depolarisation in the sarcolemma resulting in contraction of the entire muscle fibre. Thereafter the acetylcholine is quickly destroyed by the enzyme acetylcholine esterase. The presence of acetylcholine receptors has been demonstrated in the sarcolemma of the sole plate.

Nerve Endings on Smooth Muscle

Nerve fibres innervating smooth muscle are unmyelinated. They end a short distance away from the surface of the myocyte. (In other words axolemma and sarcolemma do not come into contact). At most places, the nerve fibres are covered by Schwann cell cytoplasm. However, at places this cytoplasm is retracted exposing a segment of the axon. This segment of the axon shows the presence of vesicles. Neurotransmitter released from the vesicles diffuses to the myocytes.

In sympathetic terminals, the vesicles contain catecholamines (usually noradrenaline). Monamine oxidases present in relation to sympathetic endings destroy

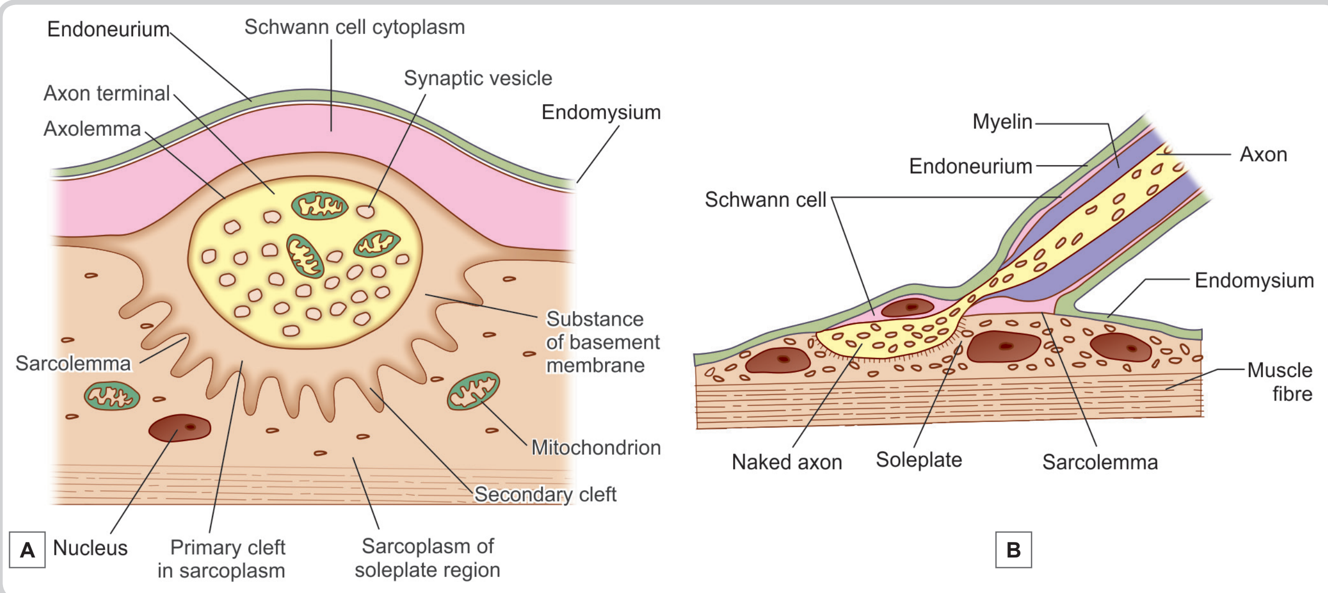


Figure 2.7: Neuromuscular junction **(A)** This figure is a section across one of the axon terminals (and related) structures shown in Figure 2.5; **(B)** Enlarged view of a muscle fibre showing the terminal naked axon lying in the surface groove of the muscle fibre

catecholamines and thus regulate sympathetic activity. At parasympathetic terminals, the vesicles in axon terminals are clear. They contain acetylcholine.

Recently it has been shown that some autonomic terminals contain neither noradrenaline nor acetylcholine. These are described as non-adrenergic non-cholinergic endings. The neurotransmitter present at these endings is probably a purine [adenosine triphosphate (ATP)]. Such fibres have been demonstrated in the walls of the alimentary and urinary tracts, and also in the CNS. These endings are believed to be predominantly inhibitory.

Other Effector Endings

Apart from muscle, effector endings are present in relation to glands (secretomotor endings), to myoepithelial cells and to adipose tissue.

Some Facts about Muscle Action

- A muscle fibre requires a stimulus for contraction to occur. Stimuli below a threshold level do not cause contraction. When a stimulus above the threshold strength is applied the muscle contracts to its full extent. This is the "***all or none law***".
- It is very important to understand that the "all or none law" applies only to individual muscle fibres and not to the muscle as a whole. The force exerted by a muscle depends on the number of muscle fibres that are in contraction at a particular moment. This allows for a graded strength of muscle action depending upon need. A corollary of this is that large muscles with greater number of fibres can exert more power than smaller muscles. The concept of motor units has been already discussed. Large muscles that are required to act with great strength have larger motor units.
- If a muscle fibre is stimulated repeatedly it fails to contract after some time. This is ***muscle fatigue***. Fatigue is caused by exhaustion of acetylcholine in the motor end plate, lack of oxygen and nutrients, and accumulation of lactic acid.
- In a resting muscle some fibres are always in a state of contraction. After some time other fibres take over this function so that fatigue does not occur. This partial contraction gives the muscle its normal state of firmness. This is called ***muscle tone***. If this tone was not present the body would collapse. Muscle tone is controlled by various reflexes based on impulses arising in muscle spindles and tendon end organs.
- When the nerve supply of a muscle is interrupted, tone is lost and the muscle becomes flaccid. Partial loss of tone is called ***hypotonia***. In upper motor neuron lesions the tone is exaggerated (***hypertonia***) and the muscle becomes rigid.
- The capacity of a muscle to maintain activity over a period of time is called ***endurance***. This depends mainly on availability of glycogen. It is increased by training, as in athletes. In most persons endurance reaches a maximum by the age of twenty, and declines after the age is fifty.
- Apart from production of muscle contraction, nerve supply has a trophic effect. This maintains the integrity of the muscle. Denervation of a muscle leads to atrophy.

The functional status of a muscle is also influenced by activity (or the lack of it). If a normal limb is immobilised

(e.g. by a plaster cast) there is some degree of atrophy and the muscles become weak. Strength can be regained by suitable exercises (physiotherapy). Similarly, normal muscles can hypertrophy and become stronger by exercise as in athletes.

SENSORY RECEPTORS

Peripheral nerves contain afferent (or sensory) fibres, and efferent (or motor) fibres. The peripheral endings of afferent nerve fibres make contact with receptors that respond to various kinds of sensory stimuli.

Classification of Sensory Receptors

The peripheral terminations of afferent fibres are responsible for receiving stimuli and are, therefore, referred to as receptors. Receptors can be classified in various ways:

I. Functional Classification

From a functional point of view, receptors can be classified on the basis of the kind of information they provide:

- ***Cutaneous receptors*** are concerned with touch, pain, temperature and pressure. These are also called ***exteroceptive receptors*** *or* ***exteroceptors.***
- ***Proprioceptive receptors (proprioceptors)*** provide information about the state of contraction of muscles, and of joint movement and position. This information is necessary for precise control of movement and for maintenance of body posture. By and large these activities occur as a result of reflex action and the information from these receptors may or may not be consciously perceived.
- ***Interoceptive receptors (interoceptors)*** are located in thoracic and abdominal viscera and in blood vessels. Those receptors in the walls of the blood vessels respond to variation in the ionic concentration of the blood (***chemoreceptors***) or variation in the blood pressure (***baroreceptors***). Such receptors are present in specialised structures like the carotid sinus and the carotid body.
- The above three categories also include receptors that are stimulated by damaging influences which are perceived as pain, discomfort or irritation. Such receptors are referred to as ***nociceptors.***
- ***Special sense receptors*** of vision, hearing, smell and taste are present in the appropriate organs. As these receptors (like those from the skin) provide information about factors external to the body they are, in a sense, exteroceptors.

II. Classification based on mode of Stimulation

Receptors may also be classified on the basis of the manner in which they are stimulated:

- ***Mechanoreceptors*** are stimulated by mechanical deformation. These include receptors for touch, pressure, stretch etc. They also include end organs in the internal ear. After receiving a stimulus some receptors quickly return to the original state and are in a position to record repeated stimulation discretely. Such receptors are termed fast-adapting. In contrast, slow-adapting receptors record repeated stimuli as if there was one continuous stimulus (e.g., that of position sense at joints).
- ***Chemoreceptors*** are stimulated by chemical influences e.g., receptors in taste buds, or in the carotid bodies.
- ***Photoreceptors*** are stimulated by light, e.g., rods and cones of the retina.
- ***Thermoreceptors*** respond to alterations in temperature.
- ***Osmoreceptors*** respond to changes in osmotic pressure.

Many receptors are polymodal in that they may respond to more than one kind of stimulus.

III. Structural Classification

A third way of classifying receptors is on the basis of their structure.

- Essentially, most receptors consist of peripheral terminations of sensory nerve fibres that receive the sensory input directly. The somata of the neurons concerned are located in spinal ganglia. As the receptor element is part of a neuron the general term ***neuronal receptor*** is applied to them.
- At some sites the sensory input is received by an epithelial cell which transmits the same to a peripheral nerve fibre. A synapse-like arrangement is seen at the junction of the epithelial cell with the axon terminal. In distinction to neuronal receptors these are termed ***epithelial receptors.***
- In the olfactory epithelium, there are ***neuroepithelial receptors***. Here, the receptor cell is a modified neuron that lies within the epithelial lining and directly gives off neuronal processes that travel centrally towards the CNS.

Although the receptor element in a neuronal receptor is a nerve terminal, such terminals are often intimately surrounded by epithelial elements as described below.

Depending upon the orientation of these epithelial elements, many types of endings have been described, but only the better known of these are given below. In the past, efforts have been made to correlate structural variations with specific sensory modalities. However, it is now realised that one type of sensation may be perceived by more than one variety of receptor. At the same time the same type of ending may subserve different functions in different locations. Finally, it is possible that the same receptor may respond to different kinds of stimuli under different circumstances. In spite of these reservations it appears reasonable to assume that some of the end organs described below are concerned predominantly with

particular sensations. It must be remembered, however, that receptors act together and not in isolation and that it is the total pattern of impulses received by the nervous system that determines the nature of the sensations perceived.

For a sensation to be perceived through a receptor three essential steps are involved. Firstly, the receptor terminal has to receive an adequate stimulus. Secondly, the stimulus has to be translated to a change in electrical potential by depolarisation of membrane. Finally, this change in potential has to excite an action potential (in the nerve fibre concerned) that travels to the CNS.

EXTEROCEPTIVE RECEPTORS

Free Nerve Endings

When the terminals of sensory nerves do not show any particular specialisation of structure, they are called free nerve endings. Such endings are widely distributed in the body. They are found in the connective tissue. They are also seen in relation to the epithelial lining of the skin, cornea, alimentary canal, and respiratory system.

Free nerve endings are particularly numerous in relation to hair follicles. They respond mainly to deformation of hair i.e., they are fast-adapting mechanoreceptors. The abundance of free nerve endings in relation to hair follicles is to be correlated with the fact that hair increases the sensitivity of skin to touch. Free nerve endings may also be thermoreceptors and nociceptors.

Some free nerve endings present in relation to hair follicles are described as ***lanceolate endings***. These terminals are seen running along the hair root, below the opening of the sebaceous duct. The terminations of the nerve fibres are flattened with sharp edges that make direct contact with epithelial cells of the hair root.

Tactile Corpuscles of Meissner (Figure 2.8)

These are small oval or cylindrical structures seen in relation to dermal papillae in the hand and foot, and in some other situations. These corpuscles are believed to be responsible for touch. They are slow-adapting mechano-receptors.

Each corpuscle is about 80 μm long and 30 μm broad. It consists of an outer capsule and a central core. The capsule is made up of several layers of greatly folded cells and is continuous with the perineurium of nerves supplying the corpuscle. The core contains cells and nerve fibres. Each corpuscle is supplied by several myelinated nerve fibres. Some unmyelinated fibres may also be present.

Lamellated Corpuscles of Pacini (Figure 2.8)

Pacinian corpuscles are circular or oval structures. These are much larger than tactile corpuscles. They may be up to

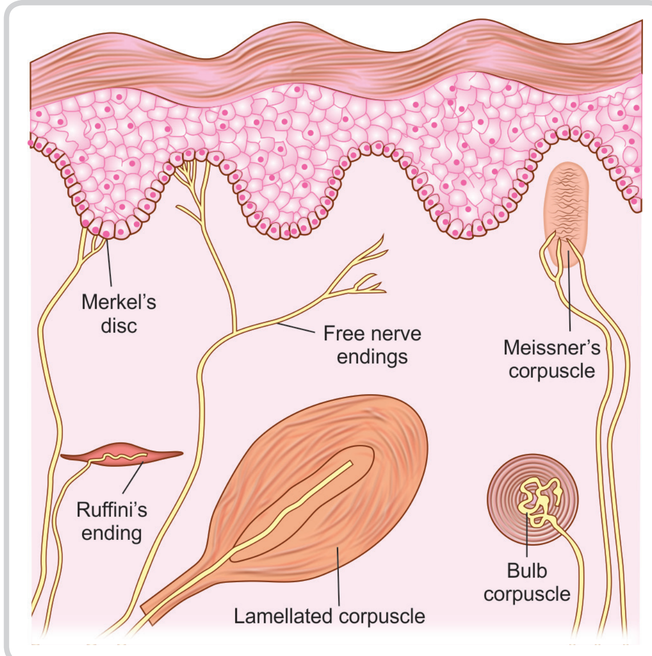


Figure 2.8: Some sensory receptors present in relation to skin (The receptors are not drawn to scale)

2 mm in length, and up to 0.5 mm across. They are found in the subcutaneous tissue of the palm and sole, in the digits, and in various other situations. Lamellated corpuscles are believed to be fast-adapting mechanoreceptors especially sensitive to vibration. They also respond to pressure.

Each corpuscle has a capsule, an intermediate zone, and a central core. The capsule is arranged in about thirty concentric layers (like the layers of an onion). The intermediate zone is cellular. The core consists of an outer layer of cells from which cytoplasmic lamellae project inwards and interdigitate with each other. In the centre of the core there is generally a single nerve fibre. The terminal part of the fibre is expanded into a bulb. Pacinian corpuscles are supplied by thick myelinated nerve fibres (Type A).

Bulbous Corpuscles of Krause (Figure 2.8)

These are spherical structures about 50 μm in diameter. They consist of a capsule within which a nerve fibre terminates in a club-shaped manner. Their significance is controversial. Some authorities regard them to be degenerating or regenerating terminals of nerve fibres rather than as specialised endings.

Tactile Menisci (Merkel Cell Receptors) (Figure 2.8)

These are small disc-like structures seen in relation to specialised epithelial cells (Merkel cells) present in the stratum spinosum of the epidermis. The discs are expanded ends of nerve fibres. Merkel cells bear spine-like protrusions that interdigitate with surrounding epidermal cells. Tactile menisci are slow-adapting mechanoreceptors

sensitive to pressure. They are supplied by large myelinated nerve fibres. Apart from surface epithelium of the skin, Merkel cell receptors may be found in relation to the sheaths of hair follicles.

Ruffini Endings (Figure 2.8)

These are spindle-shaped structures present in the dermis of hairy skin. Some are also found in non-hairy skin. Similar receptors are also present in relation to joints, in the gums, and in the glans penis.

Within a fibrocellular sheath there are collagen fibres amongst which there are numerous unmyelinated endings of myelinated nerve fibres. Ruffini endings are slow adapting cutaneous mechanoreceptors responsive to stresses in dermal collagen. They resemble the Golgi tendon organs described below.

Summary of Functions of Cutaneous Receptors

- Merkel discs and Ruffini endings are slow-adapting mechanoreceptors
- Pacinian corpuscles and some types of free nerve endings act as rapidly adapting mechanoreceptors
- Other free nerve endings act as nociceptors and thermoreceptors
- Pacinian corpuscles and Ruffini endings lie deep to skin in the dermis or in tissue deep to skin. Their receptive fields are large and sensations mediated through them are not accurately localised. Pacinian corpuscles are useful mainly for appreciation of vibration. Ruffini endings respond to stretching of the dermis
- In contrast to Pacinian corpuscles and Ruffini endings, Merkel cell receptors and Meissner's corpuscles have small receptor fields (especially over the fingers) and allow good tactile localization
- Apart from their sensory functions afferent nerve fibres may play a role in inflammation and repair of tissue, probably by releasing peptides (in particular substance P) at their endings. However, these views are not fully established at present.

PROPRIOCEPTIVE RECEPTORS

Golgi Tendon Organs

They are also called the neurotendinous organs of Golgi. These organs are located at the junction of muscle and tendon. Each organ is about 500 µm long and about 100 µm in diameter. It consists of a capsule made up of concentric sheets of cytoplasm (Figure 2.9). Inside the capsule there are small bundles of tendon fibres. The organ is innervated by one or more myelinated nerve fibres that divide to form several branches (spray-like arrangement). These receptors are stimulated by pull upon the tendon during active contraction of the muscle, and to a lesser degree by passive stretching.

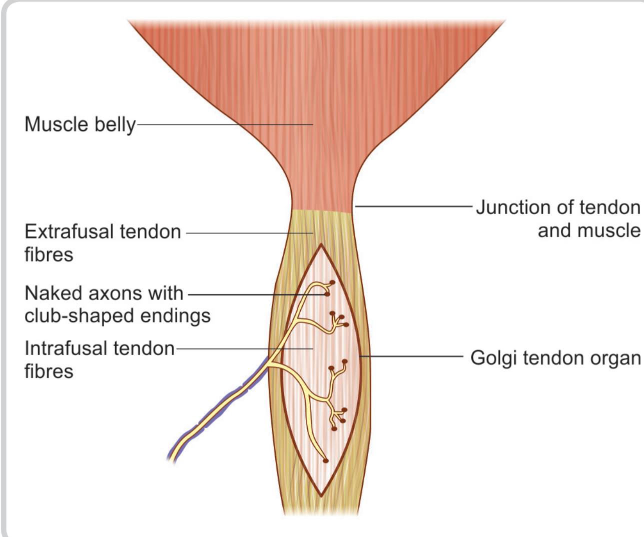


Figure 2.9: Golgi tendon organ (a neurotendinous spindle)

In the past Golgi tendon organs have been considered to be involved in myotatic reflexes that prevent the development of excessive tension in muscle. However, it is now believed that their role is mainly in providing proprioceptive information; and that they are slow adapting receptors.

Similar endings are also present in the ligaments of joints. At this site, they serve as slow-adapting, high threshold receptors. Impulses from them lead to reflex inhibition of adjacent muscles, preventing excessive stresses on ligaments.

Muscle Spindles

These are spindle-shaped sensory end organs located within striated muscle (Figure 2.10). The spindle is bounded by a fusiform connective tissue capsule (forming an external capsule) within which there are a few muscle fibres of a special kind. These are called ***intrafusal fibres*** in contrast to ***extrafusal fibres*** that constitute the main bulk of the muscle. Each spindle contains six to fourteen intrafusal fibres. Each intrafusal fibre is surrounded by an internal capsule of flattened fibroblasts and collagen.

Intrafusal fibres contain several nuclei that are located near the middle of the fibre. In some fibres this region is dilated into a bag: these are ***nuclear bag fibres***. In other intrafusal fibres the nuclei lie in a single row, there being no dilatation: these are ***nuclear chain fibres***.

Each muscle spindle is innervated by sensory as well as motor nerves. The sensory endings are of two types, primary and secondary. The motor innervation of intrafusal fibres is (mainly) by axons of gamma neurons located in the ventral grey column of the spinal cord. The sensory endings respond to stretch. Primary sensory endings are rapidly adapting while secondary endings

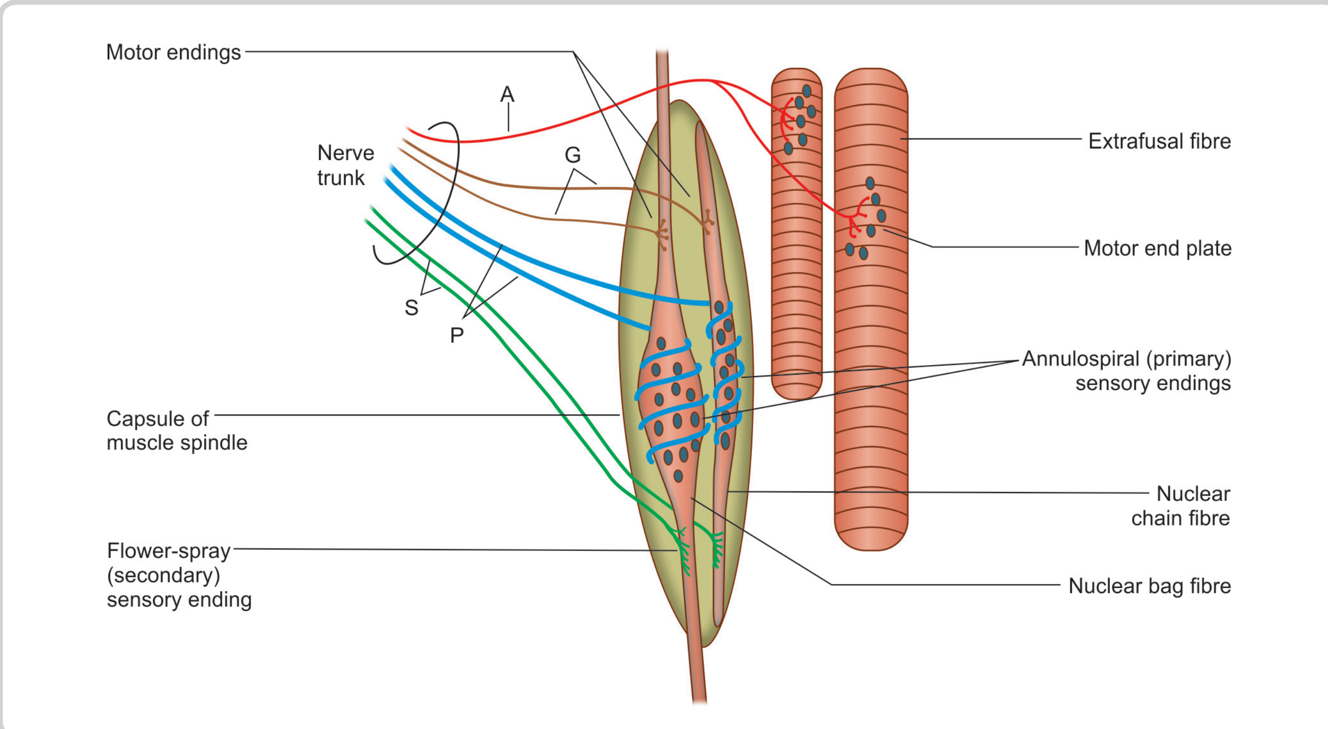


Figure 2.10: Scheme to show the structure of a muscle spindle. A—axon of alpha-neuron supplying extrafusal fibre. G= axons of gamma neurons supplying intrafusal fibres. P and S—afferents from primary and secondary sensory endings, respectively

are slow adapting. However, the precise role of these receptors is complex and varies in different types of fibres.

Spindles provide information to the CNS about the extent and rate of changes in length of muscle. Nuclear bag fibres are stimulated by rapid changes, while nuclear chain fibres react more slowly. Contraction of intrafusal fibres makes the spindle more sensitive to stretch.

The primary sensory fibres wind spirally around the nuclear region of intrafusal fibres and are, therefore, referred to as ***annulospiral endings***. The secondary endings (also called ***flower spray endings***) are seen mostly on nuclear chain fibres and are located away from the nuclear region. Both primary and secondary nerve fibres are derived from large myelinated axons, but are themselves unmyelinated.

The motor endings on intrafusal fibres of muscle spindles are of three types:

- Terminals of gamma-efferents that end on the equator of the nuclear bag, and do not show typical end plates
- Gamma-efferents ending some distance away from the equator of the nuclear bag and having typical end plates. These are also called P2 endings
- Terminals of delta-efferents (equivalent to beta-efferents of some species), which are collaterals of alpha-fibres supplying extrafusal muscle fibres. These terminals are located near the ends of nuclear bag fibres. They are also called P1 endings.

The motor nerve fibres innervating intrafusal fibres are thin but are myelinated. Those ending over nuclear bags do not show end plates. The P2 endings show typical end plates. P1 endings show en grappe end plates.

RECEPTORS PRESENT IN RELATION TO JOINTS

Four types of receptors have been demonstrated in relation to joints:

- ***Type I:*** These resemble Ruffini endings. They are innervated by myelinated nerve fibres, and serve as slowly adapting mechanoreceptors. These receptors are responsible for the sense of joint position and movement.
- ***Type II:*** These are similar to Pacinian corpuscles. They are fast-adapting mechano-receptors, supplied by myelinated nerve fibres.
- ***Type III:*** These are similar to neurotendinous organs of Golgi. Impulses arising in them are probably responsible for reflex inhibition of muscle contraction, thus preventing excessive movement.
- ***Type IV*:** These are free nerve endings, probably responsible for pain.

Clinical Correlation

- ***Myasthenia gravis:*** This is a disease marked by great weakness of skeletal muscle. The body produces antibodies against acetylcholine receptors. As a result many of these are destroyed. Transmission at the myoneural junction is much reduced resulting in weakness of muscles. Some improvement is obtained by administration of anticholine-esterase drugs like neostigmine.
- ***Neuromuscular block during administration of general anesthesia:*** Whenever a patient is administered general anaesthesia for surgery, to regulate the amount of inhaled anaesthetic drug given to the patient, the patient's respiration is taken over by the anaesthetist with the help of Ambu's bag and Boyle's machine. To do this effectively, the anaesthetist has to paralyse the patient by administering a neuromuscular blocking agent and then has to insert an endotracheal tube into the respiratory tract of the patient through which both oxygen and the anaesthetic gas are administered.

At the end of surgery, the neuromuscular blockade has to be reversed by administering an antidotal drug and the patient resumes breathing on his/her own.

Multiple Choice Questions

1. The presynaptic bag is separated from the postsynaptic process by
- A. Synaptic ribbon
- B. Synaptic cleft
- C. Synaptic glomerulus
- D. Synaptic cartridge

2. When a neuron has a direct channel of communication with an adjacent neuron, it is called as
- A. Symmetric synapse
- B. Synaptic glomerulus
- C. Electrical synapse
- D. Asymmetric synapse

3. The specialised area of the muscle with which the nerve terminal comes in contact is
- A. Motor unit
- B. Sole plate
- C. Intercalated disc
- D. Z line

4. Sensation of pain is detected by
- A. Mechanoreceptor
- B. Chemoreceptor
- C. Nociceptor
- D. Thermoreceptor

5. Which of the following is NOT an encapsulated nerve ending
- A. Merkel disc
- B. Meissner's corpuscle
- C. Ruffini corpuscles
- D. Pacinian corpuscles

6. Touch sensation is NOT conveyed by which of the following receptors
- A. Merkel disc
- B. Hair root plexus
- C. Meissner's corpuscle
- D. Pacinian corpuscle

7. Receptors present abundantly on hairless skin are
- A. Pacinian corpuscles
- B. Merkel cell receptors
- C. Meissner's corpuscles
- D. Ruffini corpuscles

8. Cutaneous receptors are
- A. Proprioceptors
- B. Interoceptors
- C. Exteroceptors
- D. None of the above

Answers

1. B **2.** C **3.** B **4.** C **5.** A **6.** D **7.** B **8.** C

Chapter **3**

Meninges and Blood Supply of Brain

Specific Learning Objectives

At the end of learning, the student shall be able to:

- Describe the meningeal coverings of brain
- Describe the blood supply of brain
- Describe the anatomical basis of clinical syndromes due to lack of blood supply
- Describe the anatomical basis of clinical conditions due to involvement of meninges
- Describe the blood-brain barrier

MENINGES

The brain and the spinal cord are covered by three layers of meninges; the outermost toughest layer is known as ***dura mater***, the next layer is known as ***arachnoid mater*** and the innermost thin layer is known as ***pia mater***. The dura mater, derived from mesoderm, is made up of dense fibrous tissue and hence it is also known as pachymeninx. It lines the bony cage in which the brain and the spinal cord are lodged. The arachnoid mater and the pia mater are derived from neural crest cells and are quite thin. Hence, these two inner layers are known as leptomeninges.

The space between the dura mater and the endosteum of the bone covering it is known as ***epidural*** or ***extradural space***. The space between the dura mater and the arachnoid mater is known as the ***subdural space***. The space between the arachnoid mater and the pia mater is known as the ***subarachnoid space*** and the space between the pia mater and the brain is known as the ***subpial space***.

Dura Mater

In the cranial cavity, the dura mater covering the brain almost fuses with the endosteum of the bones covering the brain so much so that it is described that the cranial dura mater has two layers, an outer endosteal layer and an inner meningeal layer. At certain places, the endosteal and the meningeal layers separate enclosing an endothelium-lined space filled with venous blood, the ***dural venous sinus***. ***Since the cranial dura mater fuses with the endosteal layer, there is practically no epidural or extradural space in the cranial cavity***. Only when there is a fracture of a skull bone, there is collection of blood between the dura mater and the bone causing an extradural hematoma.

Specializations of Dura Mater

The cranial dura mater forms specific dural folds which occupy major fissures on the surface of the brain. These are:

- ***Falx cerebri*** in the median longitudinal fissure of the cerebrum
- ***Tentorium cerebelli*** in the transverse fissure
- ***Falx cerebelli*** in the posterior cerebellar notch
- ***Diaphragma sellae*** bridging the interpeduncular fossa

Falx Cerebri

It is a sickle shaped dural fold present in the median longitudinal fissure of the cerebrum. It has an apex, a base, an upper convex border and a lower concave border. The apex is attached to the crista galli of the anterior cranial fossa and the base is attached to the superior surface of the tentorium cerebelli in the midline. The upper convex border is attached in front to the frontal crest, in the middle to the lips of superior sagittal sulcus and at the posterior end to the internal occipital protuberance. The lower concave border lies in the floor of the median longitudinal fissure between the two cerebral hemispheres.

Venous sinuses in relation to falx cerebri:

- ***Superior sagittal sinus*** at the upper border
- ***Inferior sagittal sinus*** at the lower border
- ***Straight sinus*** at the base
- ***Confluence of venous sinuses*** (Torcular Herophili) at the posterior end of the base.

Tentorium Cerebelli

It is a semilunar shaped fold of dura mater forming a roof over the cerebellum in the posterior cranial fossa and separates the cerebellum from the inferior surface of the occipital lobes of the cerebrum. It has a posterior attached border and an anterior free border. The posterior

border is attached to the internal occipital protuberance, margins of transverse sulci, superior border of the petrous temporal bone and the posterior clinoid processes. The anterior free border forms a 'U' shaped gap anteriorly called as **tentorial notch** through which the midbrain passes down. The free border crosses the anterior end of the posterior border and gets attached to the anterior clinoid processes.

Venous sinuses in relation to tentorium cerebelli:

- ***Right and left transverse sinuses*** at the posterior border
- ***Superior petrosal sinuses*** at the posterior border
- ***Straight sinus*** at the superior surface
- ***Confluence of venous sinuses*** at the posterior midline.

Falx Cerebelli

It is a small sickle shaped dural fold present in the posterior cerebellar notch between the two cerebellar hemispheres. The apex is attached to the vermian fossa at the foramen magnum. The base is attached to the inferior surface of the tentorium cerebelli in the midline. The anterior border is concave and free. The posterior convex border is attached to the internal occipital crest.

Venous sinuses in relation to falx cerebelli:

- **Occipital sinus** between the two layers
- **Confluence of sinuses** at the base

Diaphragma Sellae

It is a quadrangular sheet of dura mater which stretches across the sella turcica. Its anterior ends are attached to the anterior clinoid processes and its posterior ends are attached to the posterior clinoid processes. It is pierced by the infundibular stalk of the pituitary gland.

Venous sinuses in relation to diaphragma sellae:

- ***Anterior intercavernous sinus*** at its anterior border
- ***Posterior intercavernous sinus*** at its posterior border.

Nerve Supply of Dura Mater

The dura mater of anterior cranial fossa is supplied by branches of ophthalmic division of trigeminal nerve. The dura of middle cranial fossa is supplied by branches of maxillary and mandibular divisions of trigeminal nerve. The dura of posterior cranial fossa is supplied by upper three cervical nerves in the infratentorial part.

Clinical Correlation

Headache as referred pain

Any inflammation/infection in the in the area supplied by trigeminal nerve can manifest as a referred pain in the head. Similarly, since the dura of the posterior cranial fossa is supplied by cervical nerves, any inflammation in the neck region can manifest as occipital headache.

Blood Supply of Dura Mater

The dura mater of the anterior cranial fossa is supplied by meningeal branches of ophthalmic artery and from the anastomosis between the meningeal branch of ophthalmic artery and the middle meningeal artery. The dura of the middle cranial fossa is supplied by the middle meningeal artery. The dura of the posterior cranial fossa is supplied by the tentorial branch of internal carotid artery and the meningeal branch of ascending pharyngeal artery.

Clinical Correlation

The anastomosis between middle meningeal artery and the branch of ophthalmic artery is an important one between internal carotid system and the external carotid system and can act as a collateral in case of a block in one of the systems.

Arachnoid Mater

It is a thin, delicate gossamer–like membrane present deep to the dura mater covering the entire surface of the brain. Between this and the underlying pia mater there are delicate processes which connect the two layers. The adhesions look like cobweb and hence the name for this membrane is arachnoid (arachnoid means 'spider') membrane.

Specializations of Arachnoid Mater

Arachnoid membrane in the region of superior sagittal sinus modifies into small finger like projections called as ***arachnoidal villi*** which protrude into the sinus. Many such villi are grouped together is known as ***arachnoidal granulations.*** cerebrospinal fluid (CSF) produced in the ventricles circulates and reaches the subarachnoid space through the foramina in the roof of IV ventricle and then ascends up and drains through the arachnoidal villi into the superior sagittal sinus.

Pia Mater

Pia mater is the innermost delicate membrane which fits each and every crevice on the surface of the brain and is closely applied to it. Arteries entering from the subarchnoid space into the brain take a sheath of pia mater with them. Along with that a sleeve of subpial space also is present around these vessels.

Epidural or Extradural Space

This is the space between the dura mater and the surrounding bone. In the cranial cavity, since the dura fuses with the endosteum, this space is nonexistent.

Clinical Correlation

Extradural hematoma

In a case of head injury, if there is a tear of the middle meningeal artery, it results in bleeding in the space between the dura mater and the skull bone resulting in an extradural hematoma.

Subdural hematoma

In a case of head injury, if there is tear of the cerebral veins especially the bridging veins, it results in bleeding deep to the dura mater and causes subdural hematoma.

Subdural Space

This is a capillary space between the dura mater and the arachnoid mater.

Subarachnoid Space

This is a very well-developed important space between the arachnoid mater and the pia mater containing CSF. Since the pia mater is intimately applied to the brain and the arachnoid stretches over it, there are areas where the pia and the arachnoid are widely separated and in these areas pools of CSF accumulate. These are called as ***subarachnoid cisterns*** (Figure 3.1).There are some important blood vessels present in these cisterns (Table 3.1).

Major blood vessels pass through the subarachnoid space and then give branches to the brain.

Subpial Space

This is a capillary space between the pia mater and the brain. When branches of blood vessels enter the substance of brain, they carry a sleeve of pia with them and this sleeve is closed at the proximal end by a septum effectively cutting off this perivascular space of Virchow-Robin from the subarachnoid space. As the vessels pierce the pia mater and enter the brain substance, a tube of subpial space is taken along (Figure 3.2).

The nervous system is richly supplied with blood. Interruption of blood supply even for a short period can result in damage to nervous tissue. Traditionally, it has been taught that lymphatics are not present in nervous tissue, but recently this view has been challenged.

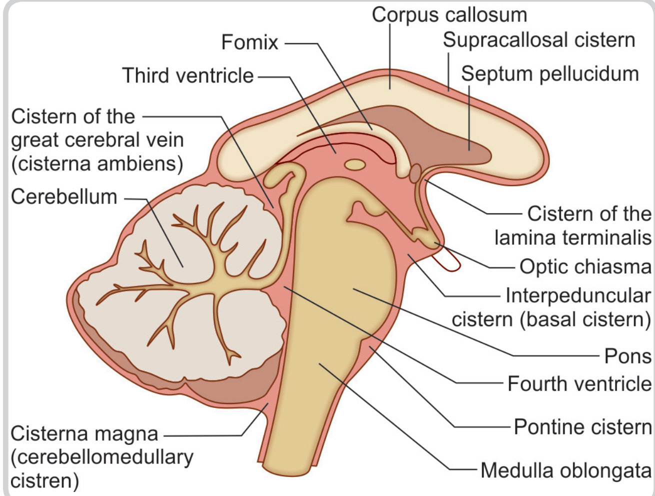


Figure 3.1: Subarachnoid cisterns

ARTERIES SUPPLYING BRAIN

The brain is supplied by two sets of arteries –**internal carotid and vertebrobasilar arteries** (Figure 3.3)**.**

Internal Carotid Arteries

Each internal carotid artery arises as one of the two terminal branches at the bifurcation of the common carotid artery in the neck at the level of C4 vertebra. The artery then ascends up in the carotid sheath and enters the cranial cavity through the carotid canal and upper part of foramen lacerum.

The course of the internal carotid artery is divisible into four parts—cervical, petrous, cavernous and cerebral.

I. ***Cervical part:*** This part of the artery is from its origin till it enters the carotid canal. This part lies entirely within the carotid sheath along with the internal jugular vein and the vagus nerve.

II. ***Petrous part:*** This part of the artery traverses the carotid canal in the petrous temporal bone.

III. ***Cavernous part:*** From the carotid canal, the artery enters the cavernous sinus through the upper part of the foramen lacerum. Here, the artery has a sinuous course and is separated from the blood in the cavernous sinus by the endothelium. This part of the artery is also called as the 'carotid siphon'. The

Table 3.1 | Subarachnoid Cisterns

Subarachnoid cistern	Location	Blood vessel present
Interpeduncular	Base of brain –interpeduncular fossa	Circle of Willis
Cerebellomedullary (cisterna magna)	Angle between the cerebellum and medulla	Posterior inferior cerebellar artery
Cisterna ambiens	Dorsal aspect of midbrain	Great cerebral vein of Galen
Basilar	Ventral surface of pons	Basilar artery
Sylvian	Over lateral sulcus	Middle cerebral artery

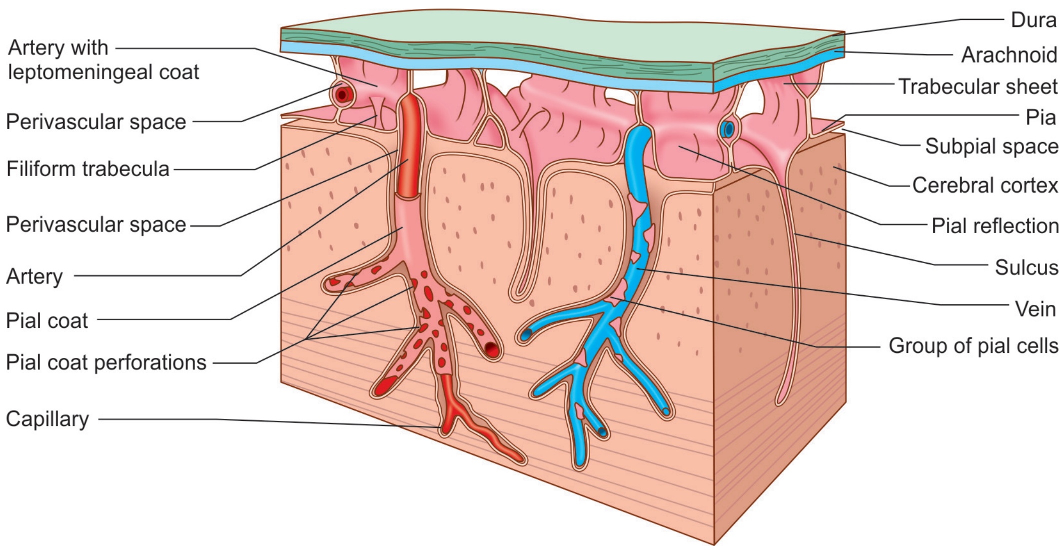


Figure 3.2: Perivascular space (Virchow-Robin space) and Subpial space

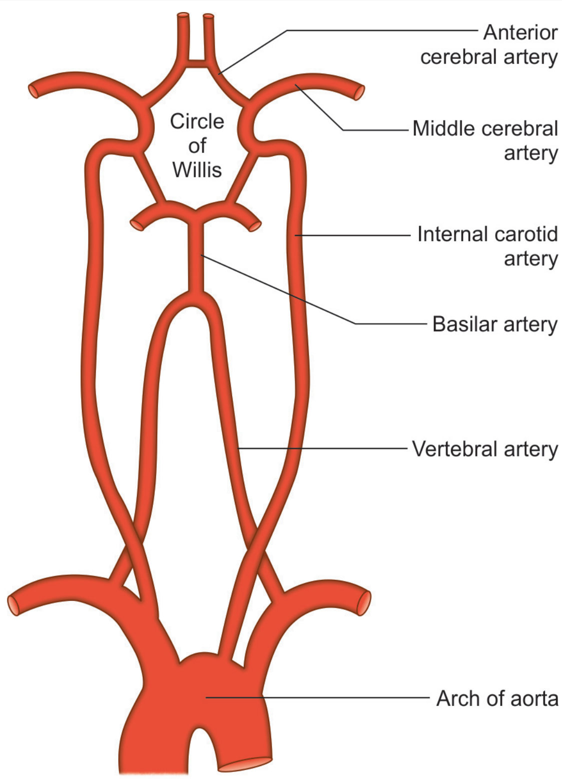


Figure 3.3: Major arteries supplying the brain.

abducent nerve is related to the internal carotid artery closely in this course.

IV. ***Cerebral part (supraclinoid part):*** At the anterior end of the cavernous sinus, the artery pierces the dura mater of the roof of the cavernous sinus and enters the subarachnoid space.

Branches of the Cerebral Part (Intracranial Part):

- ***Ophthalmic artery*:** It supplies the orbit and its contents.
- ***Anterior choroidal artery:*** It runs backwards close to the optic tract and supplies the visual pathway, internal capsule and midbrain and forms the choroid plexus of the inferior horn of lateral ventricle.
- ***Posterior communicating artery:*** This also runs backwards and anastomoses with the posterior cerebral artery, a branch of the basilar artery.
- ***Anterior cerebral artery*** and
- ***Middle cerebral artery*** which supply the entire forebrain except the occipital lobe.

Vertebrobasilar Arteries

Each vertebral artery is a branch of the first part of the subclavian artery in the neck. It ascends up in the scaleno-vertebral triangle and then passes through the foramina transversaria of upper six cervical vertebrae. At the level of atlas, the artery turns medially running horizontally on the posterior arch of atlas in the suboccipital triangle. The artery then curves around or pierces the posterior atlanto-occipital membrane and passes through the foramen magnum to enter the cranial cavity. It then pierces the dura mater to enter the subarachnoid space (Figure 3.4). The course of the vertebral artery is divisible into four parts – cervical, vertebral, suboccipital and cerebral.

I. ***Cervical part:*** This is the part of the artery from its origin till it enters the foramen transversarium of C6 vertebra. Here, the artery lies in the scaleno-vertebral triangle.

II. ***Vertebral part:*** This is the part of the artery traversing the foramina transversaria of upper six cervical vertebrae.

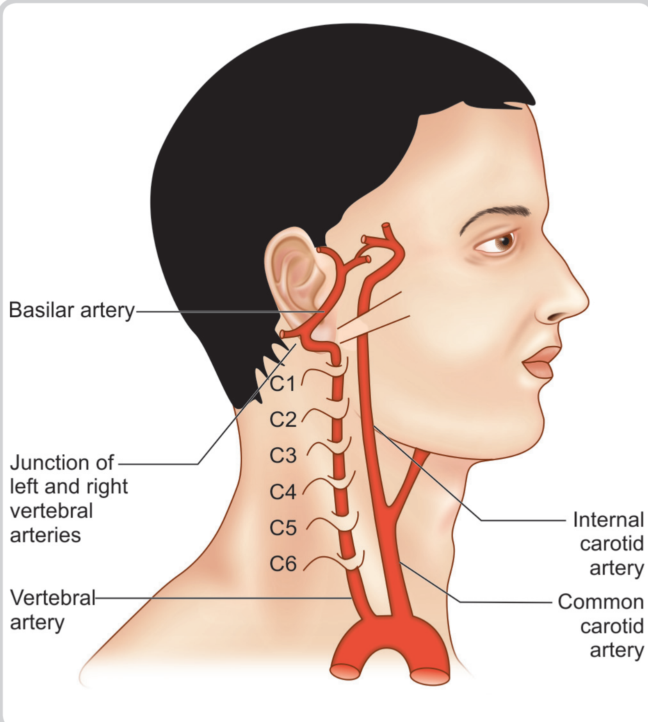


Figure 3.4: Origin and course of internal carotid and vertebral arteries

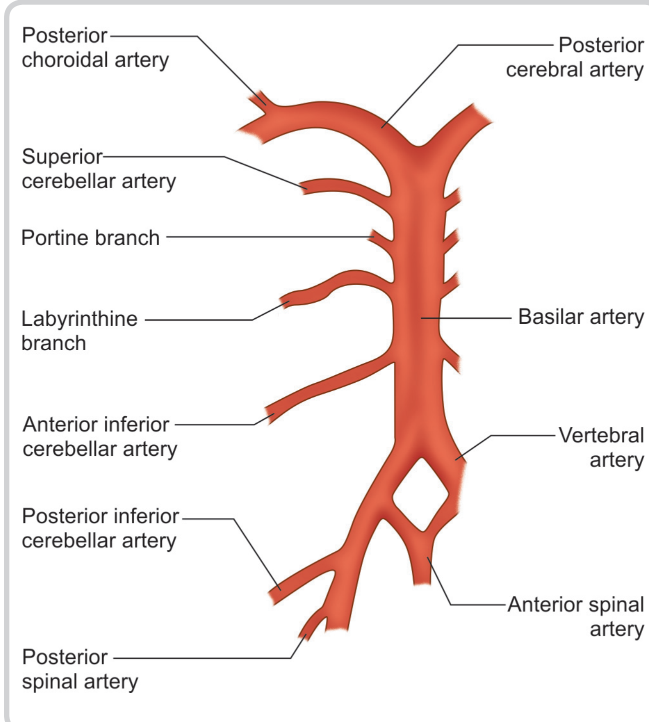


Figure 3.5: Branches of the vertebral and basilar arteries

III. ***Suboccipital part:*** This is the horizontal part of the artery lying in the suboccipital triangle.

IV. ***Cerebral part:*** This is the intracranial part of the artery lying in the subarachnoid space lateral to the medulla oblongata.

Branches of the Cerebral Part (Intracranial Part):

- ***Anterior spinal artery:*** It supplies the medial part of the medulla oblongata and then fuses with the opposite anterior spinal artery and descends to supply the spinal cord.
- ***Posterior spinal artery:*** It descends to supply the spinal cord.
- ***Posterior inferior cerebellar artery:*** It supplies the dorsolateral part of the medulla oblongata, postero-inferior part of the cerebellum and the choroid plexus of the fourth ventricle.
- ***Medullary branches:*** These branches supply directly medial part of the medulla oblongata.
- ***Meningeal branches:*** They supply the meninges of the posterior cranial fossa

The two vertebral arteries ascend up and unite at the pontomedullary junction to form the basilar artery.

The basilar artery runs in the basilar sulcus of the pons and at the pontomesencephalic junction divides into two posterior cerebral arteries.

Branches of Basilar Artery (Figure 3.5):

- ***Anterior inferior cerebellar artery:*** It supplies the anteroinferior part of the cerebellum.
- ***Labyrinthine artery:*** It supplies the inner ear.
- ***Pontine branches:*** These paramedian branches dip into the pons and supply the basilar part of the pons.
- ***Superior cerebellar artery:*** It supplies the superior surface of the cerebellum and midbrain.
- ***Posterior cerebral arteries:*** They supply the occipital lobes of the cerebrum, deep white matter, basal nuclei, diencephalon and the choroid plexus of the third ventricle and the lateral ventricle.

The branches of the vertebrobasilar system supply the spinal cord, the hindbrain, the midbrain and the occipital lobes of the forebrain.

The branches of internal carotid artery and the branches of vertebrobasilar system of arteries anastomose in the base of brain to form the arterial circle of Willis.

Circle of Willis (Circulus Arteriosus)

The circle of Willis is an arterial anastomotic circle present in the interpeduncular cistern. It is polygonal in shape and extends between the superior border of pons and median longitudinal fissure. It is closely related to the optic chiasma, tuber cinereum, mammillary bodies and posterior perforated substance. The arterial circle is an anastomosis between the internal carotid and the vertebrobasilar system of arteries (Figure 3.6).

Formation

- The anterior communicating artery, which connects the right and left anterior cerebral arteries, forms anterior part of the circle of Willis.

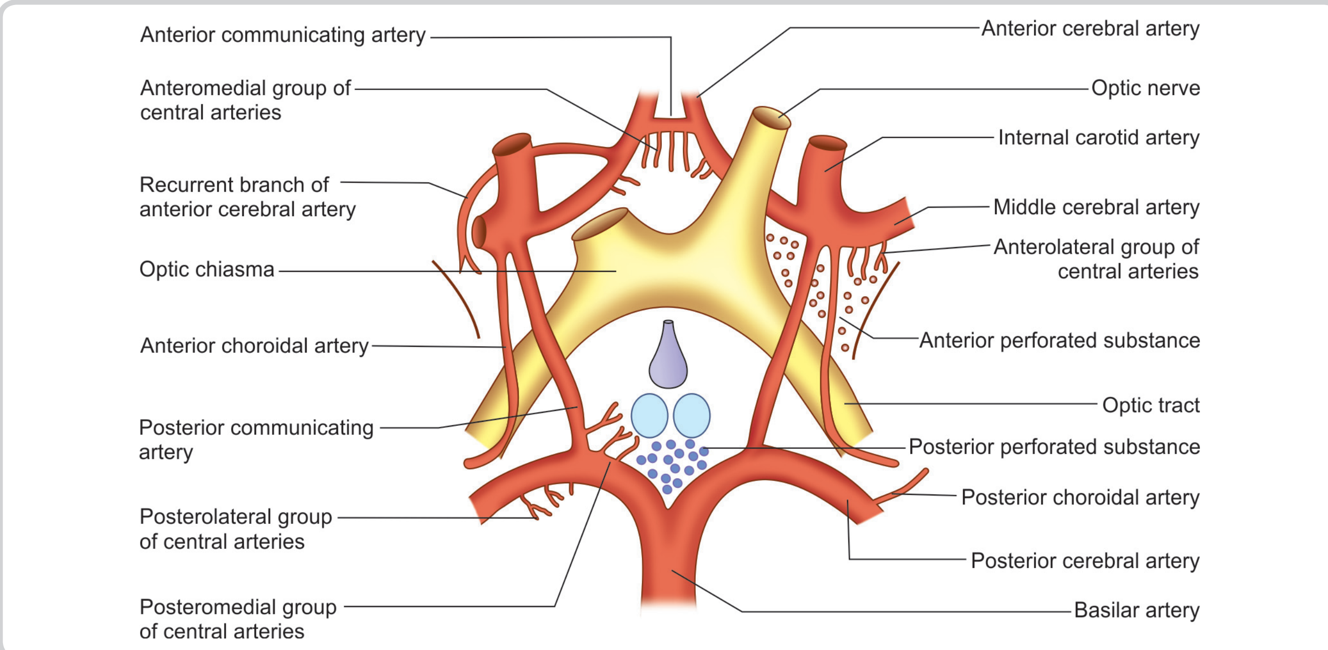


Figure 3.6: The circulus arteriosus and related structures

- The anterior cerebral artery forms the anterolateral part on each side.
- The lateral part is formed by the termination of internal carotid artery on each side.
- The circle is completed posteriorly by the bifurcation of basilar artery into the right and left posterior cerebral arteries.
- Posterolaterally, the posterior communicating artery is the connecting link between the internal carotid and posterior cerebral arteries.

Note: The middle cerebral artery does not take part in the formation of the circle of Willis.

Branches of the Circle of Willis (Figure 3.6):

- Anteromedial central branches
- Anterolateral central branches
- Posteromedial central branches
- Posterolateral central branches

These branches are described below.

Functional Imp ortance

- This arterial circle equalizes the pressure of the blood flow to the two sides of the brain, as it is the main collateral channel.
- The arterial anastomosis provides an alternative route through which blood entering the internal carotid artery or the basilar artery may be distributed to any part of the cerebral hemisphere. If one of the major arteries forming the circle of Willis is blocked, then it is through this anastomosis that blood can be supplied to the area of blocked artery.

Clinical Correlation

Berry Aneurysm

Berry aneurysm is a localized dilatation on one of the arteries of the circle of Willis due to congenital muscular weakness. The most common sites of berry aneurysm are the junction of anterior cerebral and anterior communicating arteries and at the bifurcation of internal carotid arteries. Rupture of berry aneurysm may cause life-threatening subarachnoid hemorrhage.

Branching Pattern of the Cerebral Arteries

Anterior, middle and posterior cerebral arteries give origin to two types of branches:

- Cortical
- Central

Cortical Branches

The ***cortical branches*** ramify on the surface of the cerebral hemispheres and supply the cortex. They give off branches that run perpendicularly into the substance of the cerebral hemisphere. Some of these are short and end within the grey matter of the cortex. Others are longer and penetrate into the subjacent white matter. While cortical branches may anastomose with each other on the surface of the brain, the perpendicular branches (both long and short) behave as terminal or end arteries. Each branch supplies

a limited area of brain tissue and does not anastomose with neighbouring arteries. As a result, blockage of such a branch leads to death (necrosis) of brain tissue in the region of supply.

Central Branches

The central arteries arise in the region of arterial circle of Willis and are end arteries.

They pass deep into the substance of the cerebral hemisphere to supply structures within it and consist of six main groups:

- Anteromedial
- Posteromedial
- Right and left anterolateral
- Right and left posterolateral (Figure 3.6)

The arteries of the ***anteromedial group*** arise from the anterior cerebral and anterior communicating arteries. They enter the most medial part of the anterior perforated substance.

Recurrent branch of the anterior cerebral artery (also called the ***artery of Heubner***), one of the anteromedial group of arteries, runs backwards and laterally to enter the anterior perforated substance. It supplies the caudate nucleus, anterior limb and genu of the internal capsule.

Clinical Correlation

- Thrombosis in the artery of Heubner results in contralateral paralysis of the face and upper extremity (Faciobrachial monoplegia).
- The aneurysm of internal carotid artery may compress the central part of optic chiasma and produce bitemporal hemianopia. Trauma to the internal carotid artery in cavernous sinus leads to the formation of arteriovenous fistula, causing pulsating exophthalmos.
- The internal carotid artery shows multiple bends, which produce S-shaped shadow called the carotid siphon on an angiogram. The carotid siphon helps in damping down its pulsations in the cranial cavity.

The arteries of the ***anterolateral group*** are the so-called ***striate arteries***. They arise mainly from the middle cerebral artery. Some of them arise from the anterior cerebral artery. The anterolateral group of perforating arteries enter the anterior perforated substance and divide into two sets, medial and lateral. The ***medial striate arteries*** ascend through the lentiform nucleus. They supply this nucleus and also the caudate nucleus and the internal capsule. The ***lateral striate arteries*** (***lenticulostriate***) ascend lateral to the lower part of the lentiform nucleus; they then turn medially and pass through the substance of the lentiform nucleus to supply the internal capsule and the caudate nucleus. One of these lateral striate arteries is usually larger than the others. It is called ***Charcot's artery of cerebral hemorrhage***.

The ***posteromedial group*** of central arteries arise from the posterior communicating artery and the proximal part of the posterior cerebral artery. They enter the posterior perforated substance in the interpeduncular region. They are also called as ***thalamoperforators.*** They supply the hypophysis, Infundibulum, tuber cinereum, mammillary bodies, anterior and medial groups of thalamic nuclei, subthalamic region and tegmentum of midbrain.

The central branches of the ***posterolateral group*** arise from the lateral part of the posterior cerebral artery, as it winds around the cerebral peduncle. They are also called as ***thalamogeniculate arteries.*** They supply the caudal half of thalamus, pulvinar, medial and lateral geniculate bodies, the lateral and the large ventral groups of thalamic nuclei.

Clinical Correlation

- Occlusion of lenticulostriate arteries results in loss of blood supply to internal capsule leading to contralateral spastic hemiplegia, paralysis of lower half of face, and altered sensorium.
- ***Charcot-Bouchard aneurysms*** (Figure 3.7) are the microaneurysms of the lenticulostriate arteries in the presence of long-standing hypertension. Their rupture results in cerebral hemorrhage.

Anterior Cerebral Artery

This artery arises from the internal carotid artery below the anterior perforated substance and lateral to the optic chiasma. It crosses the optic chiasma to reach the median longitudinal fissure. At the anterior end of the longitudinal fissure, the anterior communicating artery connects the right and left anterior cerebral arteries. Inside the longitudinal fissure, the anterior cerebral artery winds round the genu and then runs posteriorly on the superior aspect of the body of corpus callosum.

Cortical Branches

- Orbital branches
- Frontopolar branch
- Callosomarginal branch
- Pericallosal branch

Distribution

- The orbital branches supply the medial half of orbital surface of the frontal lobe (olfactory bulb, olfactory gyrus, and medial olfactory gyri).
- The frontopolar branch supplies the anteriormost part of the frontal lobe on the inferior surface.
- The callosomarginal and pericallosal branches supply the medial surface of the frontal and the parietal lobes including the paracentral lobule, cingulate gyrus, corpus callosum and the precuneus of the parietal lobe.

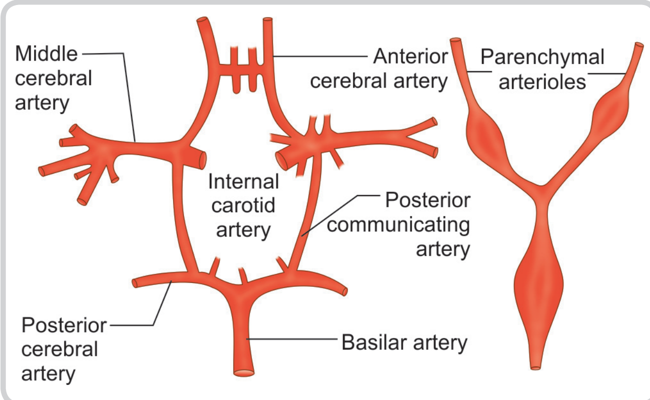


Figure 3.7: Charcot-Bouchard aneurysms.

The anterior cerebral artery supplies the medial part of orbital surface of frontal lobe and the medial surfaces of frontal and parietal lobes. It also supplies 1–2 cm of the superolateral surface (of the frontal and parietal lobes) adjacent to superomedial border upto the parieto-occipital sulcus. The functional areas that receive blood from anterior cerebral artery are the motor and sensory areas for lower limb and perineum.

Clinical Correlation

Effects of occlusion of anterior cerebral artery

- Paralysis (or weakness) of muscles of the leg and foot of the opposite side (by involvement of the upper part of the motor area)
- Loss (or dulling) of sensations from the leg and foot of the opposite side (by involvement of the upper part of the sensory area)
- Sense of stereognosis is impaired (by involvement of parietal lobe)
- Personality changes (by involvement of frontal lobe)

Middle Cerebral Artery

It is one of the terminal branches of the internal carotid artery. It turns laterally on the anterior perforated substance to enter the stem of the lateral sulcus, where it divides into four to five cortical branches on the surface of insula.

Cortical Branches

- Anterior temporal branch
- Orbitofrontal branch
- Pre-Rolandic or precentral branch
- Rolandic or Central branch
- Post-Rolandic or Postcentral or Anterior parietal branch
- Posterior parietal branch
- Posterior temporal branch

Distribution

- The orbitofrontal branches supply the lateral half of orbital surface of frontal lobe.
- The frontal branches, i.e. the precentral and central branches supply the superolateral surface of frontal lobe (precentral, middle, and inferior frontal gyri) excluding the area supplied by anterior cerebral artery.
- The parietal branches supply the postcentral gyrus, inferior parietal lobule, and superior parietal lobule, excluding the area supplied by the anterior cerebral artery.
- The temporal branches supply the lateral surface of the temporal lobe excluding the inferior temporal gyrus but including the temporal pole.

The functional areas that receive blood from the middle cerebral artery are the motor and sensory areas (upper limb, trunk, and face), premotor area, frontal eye field, auditory area, and the speech centres in the dominant hemisphere.

Clinical Correlation

Effects of occlusion of middle cerebral artery

- Hemiplegia and loss of sensations on the opposite half of the body. The face and arms are most affected. Foot and leg are spared.
- Aphasia (by involvement of Broca's and Wernicke's areas), especially if the thrombosis is in the left hemisphere in a right-handed person.
- Homonymous hemianopia on the opposite side (by involvement of optic radiation).
- Hearing may be affected, but this may be compensated by the opposite hemisphere.

Posterior Cerebral Artery

The right and left posterior cerebral arteries are the terminal branches of basilar artery. Each passes laterally around the crus cerebri of the midbrain, where it receives the posterior communicating artery. It continues along the lateral aspect of the midbrain and enters the supratentorial compartment through the tentorial notch. Then, it courses on the tentorial surface of the brain giving out its branches.

Cortical Branches

- Posterior temporal branch (Temporo-occipital branch)
- Internal occipital branch (divides into parieto-occipital branch and calcarine branch)

Distribution

- The posterior temporal branch supplies the inferior surface of temporal lobe, uncus, and occipitotemporal and lingual gyri. It also sends twigs to the inferior temporal gyrus excluding the temporal pole.
- The calcarine and parieto-occipital branches supply the medial surface of the occipital lobe, which includes the cuneus. These cortical branches send twigs to superolateral surface of the occipital lobe.

The visual cortex is the important functional area supplied by the posterior cerebral artery. The occipital pole which represents the macular region of the retina receives blood from the anastomosis between the branches of posterior and middle cerebral arteries. Therefore, in the occlusion of the posterior cerebral artery, there is macular sparing because of the supply from the middle cerebral artery and hence macular vision is preserved.

Clinical Correlation

Effects of occlusion of posterior cerebral artery

- The loss of cortical supply results in contralateral homonymous hemianopia with macular sparing. Damage to association cortex of visual area causes visual hallucinations (distortion of colour vision).
- The part of the visual area responsible for macular vision lies in the region, where the territories of supply of the middle and posterior cerebral arteries meet. It may receive a supply from the middle cerebral artery, either directly or through anastomoses with branches of the posterior cerebral artery. This is one explanation for the observation that macular vision is often spared in cases of thrombosis of the posterior cerebral artery. The phenomenon can also be explained by the observation that dye injected into the carotid system (for angiographic studies) often passes into the posterior cerebral artery through the posterior communicating artery.

Note: From the description given above, it will be clear that the main somatic motor and sensory areas are supplied by the middle cerebral artery, except in their uppermost parts (leg areas), which are supplied by the anterior cerebral artery. The auditory area is supplied by the middle cerebral artery and the visual area, by the posterior cerebral artery.

VENOUS DRAINAGE OF BRAIN

The veins draining the brain open into the dural venous sinuses (Figure 3.8). These are the ***superior sagittal, inferior sagittal, straight, transverse, sigmoid, cavernous, sphenoparietal, petrosal,*** and ***occipital sinuses***. Ultimately, the blood from all these sinuses reaches the sigmoid sinus, which becomes continuous with the ***internal jugular vein*** on either side. The intracranial venous sinuses communicate with the veins outside the skull through emissary veins.

The veins draining the brain are valveless and thin walled because their walls are devoid of muscles.

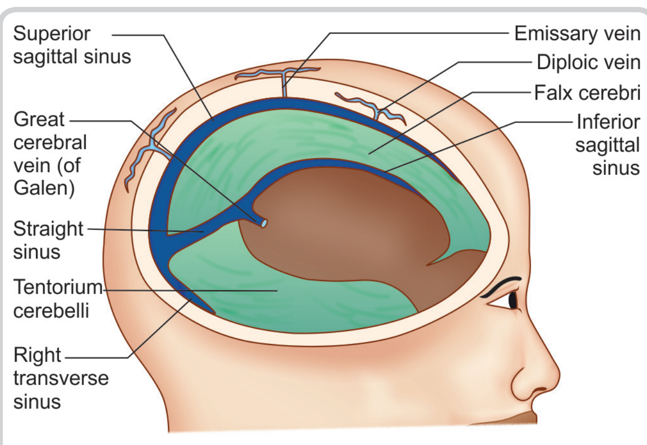


Figure 3.8: Venous drainage of brain

Veins of the Cerebral Hemisphere

The veins of the cerebral hemisphere consist of two sets, superficial and deep. The superficial veins lie in the subarachnoid space on the surface of the cerebral hemisphere and drain mainly into the superior sagittal sinus, which ultimately drain into the right internal jugular vein. On the other hand, the deep veins drain mainly into the ***great cerebral vein***, which ultimately drains into left internal jugular vein (Table 3.2).

Superficial Cerebral Veins

The superficial veins drain into neighboring venous sinuses (Figure 3.9). The ***superior cerebral veins*** drain the upper parts of the superolateral and medial surfaces and end in the superior sagittal sinus. Some veins from the medial surface join the inferior sagittal sinus. ***Inferior cerebral veins*** drain the lower part of the hemisphere. On the superolateral surface, they drain into the ***superficial middle cerebral vein,*** which lies superficially along the lateral sulcus and its posterior ramus. The posterior end of this vein is connected to the superior sagittal sinus by

Table 3.2 | **Veins of the Cerebrum**

Superficial cerebral veins	Deep cerebral veins
Superior cerebral veins	Internal cerebral veins
Inferior cerebral veins	Basal veins
Superficial middle cerebral vein	Thalamostriate vein
Superior anastomotic vein	Great cerebral vein
Inferior anastomotic vein	

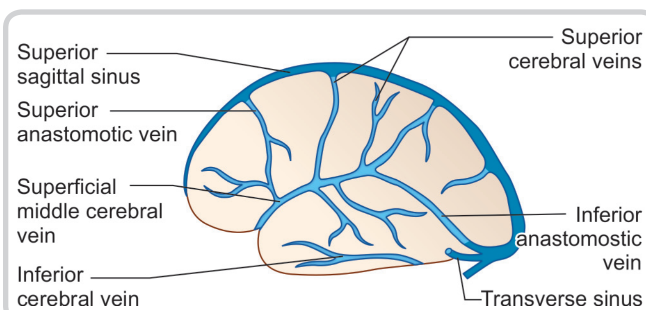


Figure 3.9: Superior cerebral veins on the superolateral surface of the cerebrum

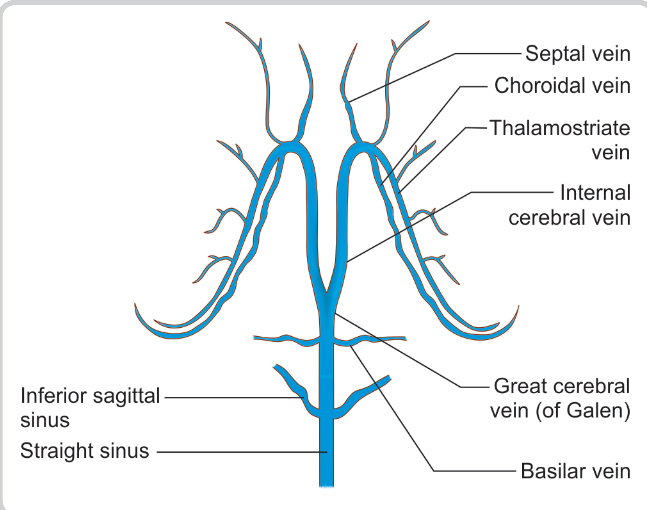


Figure 3.10: Deep cerebral veins

the ***superior anastomotic vein*** and to the transverse sinus by the ***inferior anastomotic vein.*** The superficial middle cerebral vein terminates in the cavernous sinus. Veins from the inferior surface of the cerebral hemisphere drain into the transverse, superior petrosal, cavernous, and sphenoparietal sinuses. Some may ascend to join the inferior sagittal sinus.

Deep Cerebral Veins

The deep veins of the cerebral hemisphere are the two ***internal cerebral veins*** that join to form the ***great cerebral vein*** and the two ***basal veins*** that wind round the midbrain to end in the great cerebral vein (Figure 3.10).

Each internal cerebral vein begins at the interventricular foramen and runs backwards in the tela choroidea in the roof of the third ventricle. It has numerous tributaries. One of these is the ***thalamostriate vein,*** which lies in the floor of the lateral ventricle (between the thalamus, medially and the caudate nucleus, laterally). Each basal vein begins near the anterior perforated substance. It is formed by union of the following:

- The ***anterior cerebral vein***, which accompanies the anterior cerebral artery
- The ***deep middle cerebral vein***, which lies deep in the stem and posterior ramus of the lateral sulcus
- Some ***inferior striate veins*** that emerge from the anterior perforated substance

The great cerebral vein, formed by the union of the two internal cerebral veins, passes posteriorly beneath the splenium of the corpus callosum to end in the straight sinus. It receives the basal veins, some veins from the occipital lobes, and some from the corpus callosum.

The deep cerebral veins described above are responsible for draining the thalamus, hypothalamus, corpus striatum, internal capsule, corpus callosum, septum pellucidum, and choroid plexuses. Many tributaries of the internal cerebral veins extend beyond the corpus striatum into the white matter of the hemispheres. Here, they establish communications with superficial veins. They can, thus, serve as alternative channels for draining parts of the cerebral cortex. Flowchart depicting the venous drainage of cerebral hemisphere is shown in Figure 3.11.

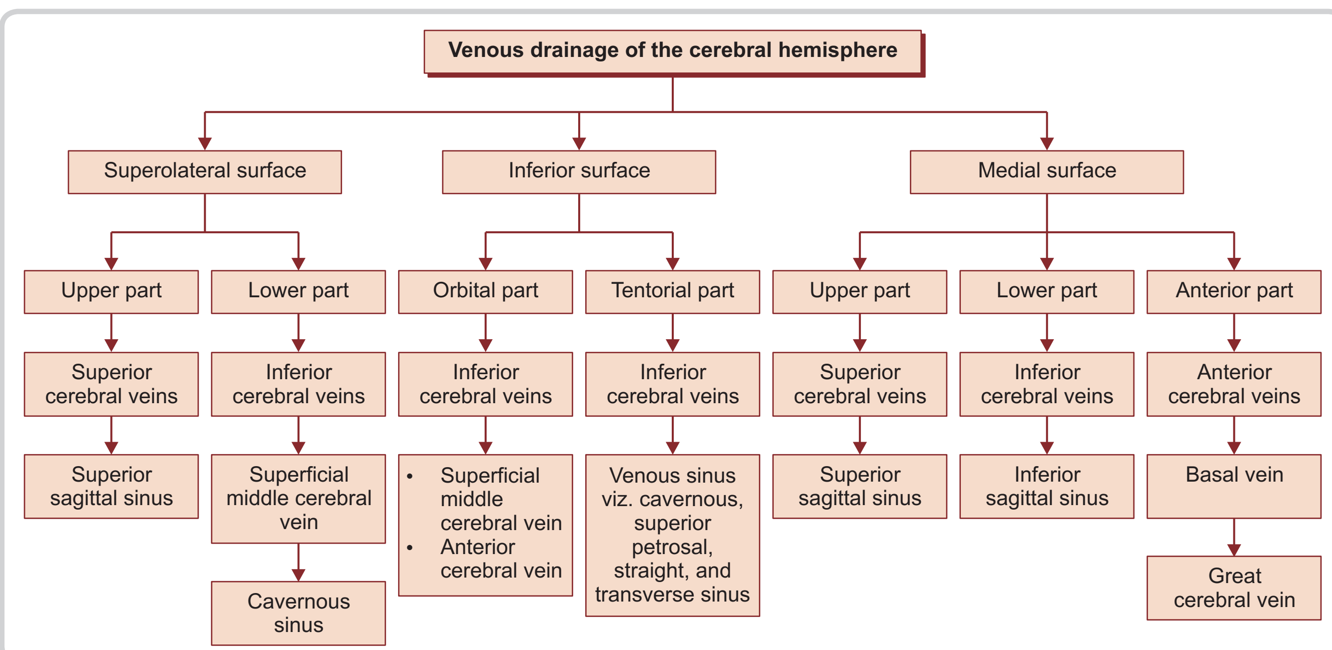


Figure 3.11: Venous drainage of cerebral hemisphere

Venous Drainage of Other Parts of the Brain

The upper part of the ***thalamus*** is drained by the tributaries of the internal cerebral vein (including the thalamostriate vein). The lower part of the thalamus and the hypothalamus are drained by veins that run downwards to end in a plexus of veins present in the interpeduncular fossa. This plexus drains into the cavernous and sphenoparietal sinuses and into the basal veins.

The ***corpus striatum*** and ***internal capsule*** are drained by two sets of striate veins. The ***superior striate veins*** run dorsally and drain into tributaries of the internal cerebral vein. The ***inferior striate veins*** run vertically downwards and emerge on the base of the brain through the anterior perforated substance. Here, they end in the basal vein.

Veins of the Cerebellum and Brainstem

The veins from the upper surface of the ***cerebellum*** drain into the straight, transverse, and superior petrosal venous sinuses. Veins from the inferior surface drain into the right and left sigmoid, inferior petrosal sinuses, occipital sinus, and straight sinus.

The veins of the ***midbrain*** drain into the great cerebral vein or into the basal vein. The ***pons*** and ***medulla*** drain into the superior and inferior petrosal sinuses, transverse sinus, and occipital sinus. Inferiorly, the veins of the medulla are continuous with the veins of the spinal cord.

BLOOD-BRAIN BARRIER

It has been observed that while some substances can pass from the blood into the brain with ease, others are prevented from doing so. This has given rise to the concept of a selective barrier between blood and the brain.

Structure of Blood-brain Barrier

Anatomically, the structures that constitute the barrier are as follows (Figure 3.12).

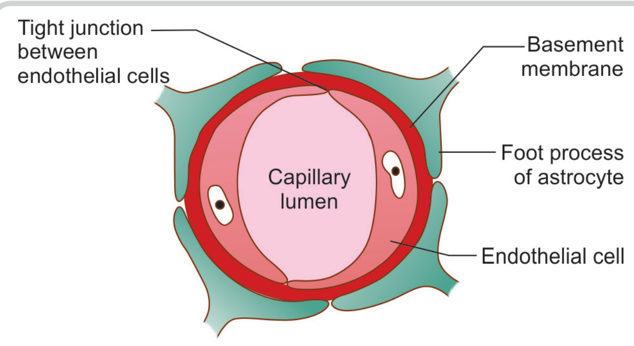


Figure 3.12: Structure of blood-brain barrier

- Capillary endothelium
- Basement membrane of the endothelium
- Closely applied to the vessels, there are numerous processes of astrocytes. It has been estimated that these processes cover about 85% of the capillary surface.

Areas of the Brain Devoid of Blood-brain Barrier

Some areas of the brain appear to be devoid of a blood-brain barrier. These include:
- Pineal body
- Neurohypophysis
- Organum Vasculosum of Lamina Terminalis (OVLT)
- Median eminence (hypothalamus)
- Subcommissural organ
- Subfornical organ
- Area postrema

These are also called as Circumventricular Organs (CVOs) as these are specialised areas in the walls of third and fourth ventricles (Further details are given in chapter 17).

Clinical Correlation

The blood-brain barrier can break down following ischemia or infection in the brain. The barrier can also break down in trauma and through the action of toxins. Some drugs, including some antibiotics, can pass through the barrier while others cannot.

In infants, bilirubin can pass through the barrier. There is a danger of encephalitis, if bilirubin levels are high (seen as jaundice in the newborn or ***kernicterus***).

Traditionally, it has been taught that the subarachnoid space is continuous with perivascular spaces (present around blood vessels passing into the brain). However, it has now been shown that the perivascular spaces and the subpial space are completely cut off from the subarachnoid space by pia mater (which is reflected onto arteries as a sleeve) (Figure 3.2). The pia mater, therefore, contributes to the establishment of the blood-brain barrier.

Control of Cerebral Blood Flow

Cerebral blood flow is influenced by sympathetic nerves (which are present around arteries as they pass through the subarachnoid space). Adrenergic nerve fibres within the brain also end on blood vessels.

Blood flow through the brain does not markedly vary with alterations in blood pressure. Blood flow through a part of the brain increases, when that part is "active". Such areas can be visualized by using the technique of ***positron emission tomography*** (PET). Studies using the technique are throwing much light on functions of various areas. PET can be combined with ***magnetic resonance imaging*** (MRI) to provide accurate localization of the areas showing altered blood flow.

Multiple Choice Questions

1. The venous sinus that is present at the base of falx cerebri is
   A. Occipital
   B. Straight
   C. Inferior sagittal
   D. Cavernous
2. The branch of internal carotid artery that supplies the optic tract is
   A. Anterior choroidal
   B. Middle cerebral
   C. Posterior cerebral
   D. Posterior communicating
3. Which artery lies in the pontine cistern?
   A. Superior cerebellar
   B. Basilar
   C. Posterior cerebral
   D. Anterior inferior cerebellar
4. The vessel that lies in the ambient cistern is
   A. Superior cerebellar artery
   B. Basal vein
   C. Anterior choroidal artery
   D. Great cerebral vein
5. The medial surface of the cerebral hemisphere upto parieto-occipital sulcus is supplied by which artery
   A. Anterior cerebral
   B. Middle cerebral
   C. Medial striate
   D. Posterior cerebral
6. Which of the following areas of the brain shows blood-brain barrier?
   A. Median eminence of hypothalamus
   B. Hypophysis cerebri
   C. Choroid plexus of ventricles
   D. Tectum of midbrain
7. Which of the following veins is related to the transverse fissure of the brain?
   A. Basal
   B. Superficial middle cerebral
   C. Great cerebral
   D. Deep middle cerebral
8. The great cerebral vein is formed by the union of
   A. Superficial middle cerebral veins
   B. Deep middle cerebral veins
   C. Internal cerebral veins
   D. Inferior cerebral veins
9. The superficial middle cerebral vein ends in the
   A. Superior sagittal sinus
   B. Inferior sagittal sinus
   C. Transverse sinus
   D. Cavernous sinus

Answers

1. B **2.** A **3.** B **4.** D **5.** A **6.** D **7.** C **8.** C **9.** D

Chapter **4**

Development of Central Nervous System

Specific Learning Objectives

At the end of learning, the student shall be able to:
- Describe the formation and histogenesis of neural tube
- Describe the development of prosencephalon, mesencephalon and rhombencephalon, their derivatives and curvatures
- Enumerate the derivatives of neural crest cells
- Correlate the embryological basis of relevant congenital anomalies—anencephaly, hydrocephalus, spina bifida, meningocele, and meningomyelocele

The whole of the nervous system is derived from ectoderm of the embryo, except its blood vessels and some neuroglial elements.

FORMATION OF NEURAL TUBE

At the time when the nervous system begins to develop, the embryo is in the form of a three-layered disk, i.e. the gastrula (Figures 4.1 and 4.2). In the midline, prochordal plate is placed cranially and the primitive streak caudally. The cranial end of the primitive streak is thickened. This thickened cranial end is called the ***primitive knot***. Between the prochordal plate and primitive knot the ***notochord*** develops. The notochord lies between ectoderm and endoderm.

The part of the ectoderm that is destined to give origin to the brain and spinal cord is situated on the dorsal aspect of the embryonic disk, in the midline and overlies the developing notochord (Figure 4.3A). It soon becomes thickened to form the ***neural plate*** (Figure 4.3B).

The neural plate becomes depressed along the midline, as a result of which the ***neural groove*** is formed (Figure 4.3C). This groove becomes progressively deeper. By the end of third week, the two raised edges of the neural plate, which are called ***neural folds***, come near each other and eventually fuse, thus converting the neural groove into the ***neural tube*** (Figure 4.3D). The neural tube is formed from the ectoderm overlying the notochord and, therefore, extends from the prochordal plate to the primitive knot (Figure 4.2). The process of formation of the neural tube is referred to as ***neurulation***.

These stages in the formation of the neural tube do not proceed simultaneously all over the length of the neural plate. The middle part is the first to become tubular, so that for some time, the neural tube is open cranially and caudally. These openings are called the ***anterior*** and ***posterior neuropores***, respectively. The fusion of the two edges of the neural plate extends cranially and caudally, and eventually, the neuropores disappear leaving a closed tube.

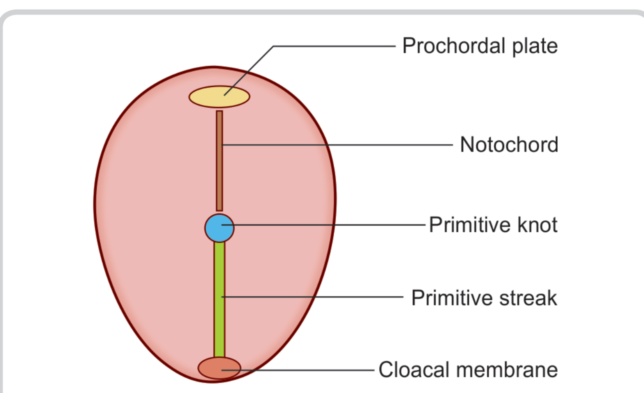


Figure 4.1: Early embryonic disc before formation of the neural plate

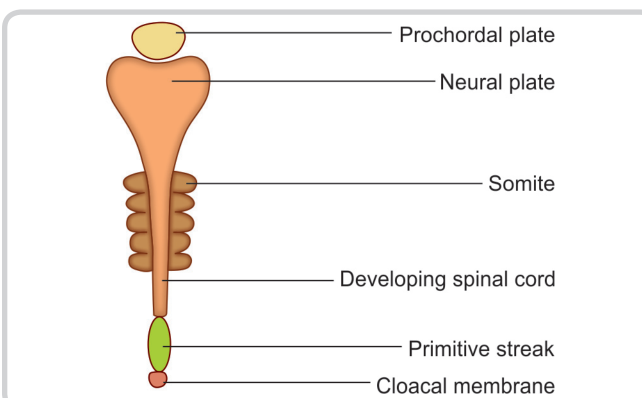


Figure 4.2: Embryonic disc showing the neural plate

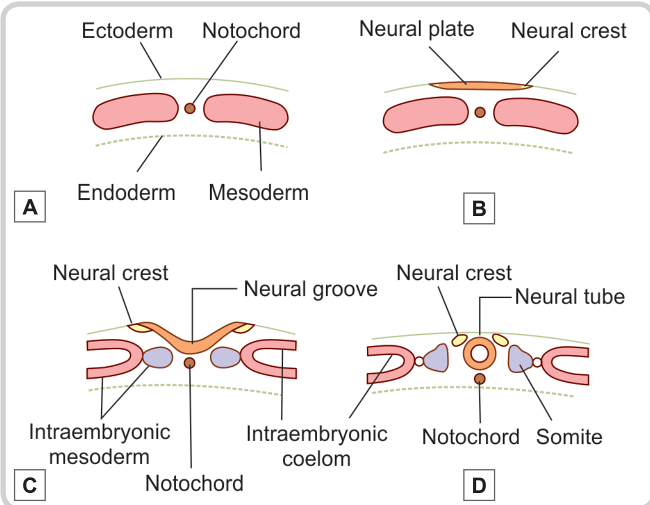


Figure 4.3: Formation of neural tube (**A**) Embryonic disc before formation of neural plate (**B**) Neural plate formed by thickening of ectoderm (**C**) Neural plate is converted to a groove (**D**) The groove is converted to a tube. Note the neural crest which lies along the edges of the neural plate (B), or neural groove (C) After formation of the neural tube the neural crest lies dorsal to it (D)

Even before the neural tube has completely closed, it is divisible into an enlarged cranial part and a caudal tubular part (Figure 4.2). The enlarged cranial part forms the ***brain***. The caudal tubular part forms the ***spinal cord***. It is at first short but gradually gains in length as the embryo grows.

Clinical Correlation

Faulty formation of neural tube

- The whole length of the neural tube remains unclosed. This results in the condition called ***posterior rachischisis***.

Contd...

- The neural tube remains open in the region of the brain. This results in ***anencephaly***. Brain tissue which is exposed degenerates.
- Nonfusion of the neural tube is associated with nonclosure of the cranium (***cranium bifidum***) or of the vertebral canal (***spina bifida***).
- The brain may be too small (***microcephaly***) or too large (***macrocephaly***).
- Parts of the nervous system may be absent.

FORMATION OF NEURAL CREST

At the time when the neural plate is being formed, some cells at the junction between the neural plate and the rest of the ectoderm become specialized (on either side) to form the primordia of the neural crest (Figures 4.3B and C). With the separation of the neural tube from the surface ectoderm, the cells of the neural crest appear as groups of cells lying along the dorsolateral sides of the neural tube (Figure 4.3D). The neural crest cells soon become free (by losing the property of cell-to-cell adhesiveness). They migrate to distant places throughout the body. In subsequent development, several important structures are derived from the neural crest. These include some neurons of sensory and autonomic ganglia, Schwann cells, and possibly, the pia mater and the arachnoid mater. Many other derivatives of the neural crest are recognized in widespread tissues (Figure 4.4).

Clinical Correlation

Several diseases and syndromes are associated with the disturbances of the neural crest, i.e. Hirschsprung's disease (aganglionic megacolon), aorticopulmonary septal defects of heart, cleft lip, cleft palate, frontonasal dysplasia, neurofibromatosis, tumor of adrenal medulla, and albinism, etc.

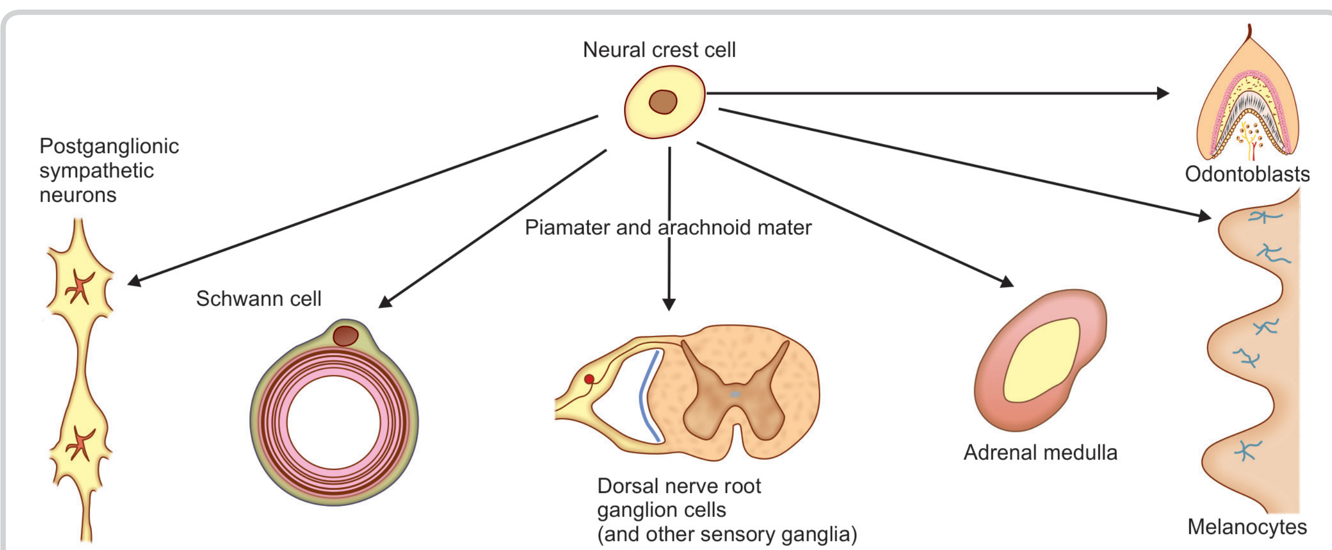


Figure 4.4: Structures derived from neural crest cells

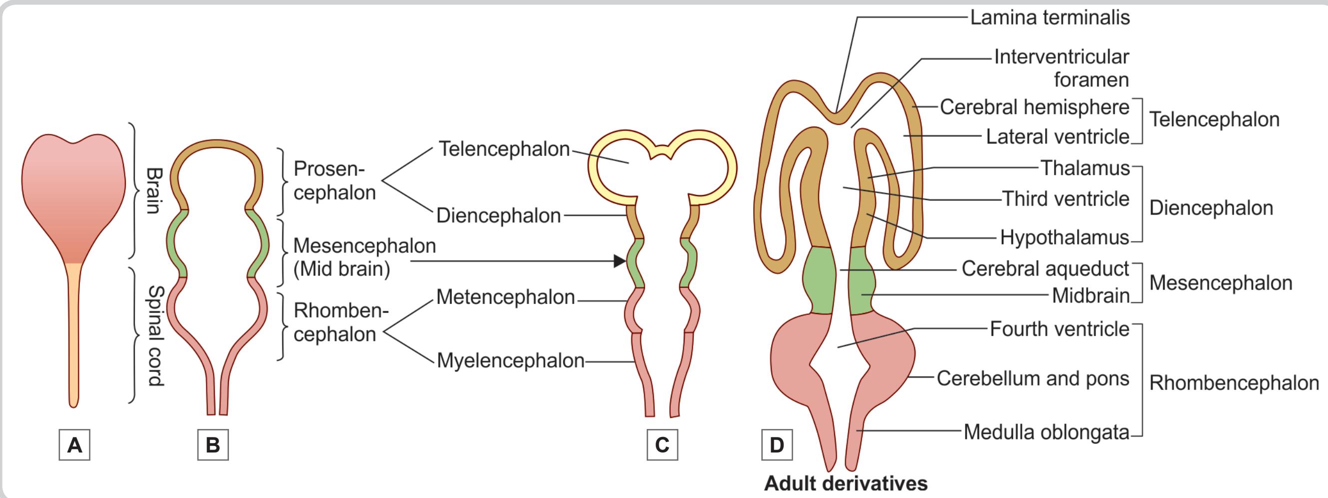


Figure 4.5: Schematic diagram to show stages in the development of brain vesicles and the ventricular system

Subdivisions of Neural Tube

Even before the complete closure of the neural tube, it is divisible into an enlarged cranial part and a caudal tubular part (Figure 4.2). The enlarged cranial part forms the brain. The caudal tubular part forms the spinal cord. It is at first short but gradually gains in length as the embryo grows.

DEVELOPMENT OF BRAIN

The brain develops from the enlarged cranial part of the neural tube (Figure 4.5A). At about the end of fourth week, the cavity of the developing brain shows three dilatations (Figure 4.5B). Craniocaudally, these are the ***prosencephalon (forebrain vesicle)***, ***mesencephalon (midbrain vesicle)***, and ***rhombencephalon (hindbrain vesicle)***. The prosencephalon becomes subdivided into the ***telencephalon*** and the ***diencephalon*** (Figure 4.5C). The telencephalon consists of right and left ***telencephalic vesicles.*** The rhombencephalon also becomes subdivided into a cranial part, the ***metencephalon***, and a caudal part, the ***myelencephalon***. The parts of the brain that are developed from each of these divisions of the neural tube are shown in Figures 4.5D and 4.6.

FLEXURES OF BRAIN

The prosencephalon, mesencephalon, and rhombencephalon are at first arranged craniocaudally (Figure 4.7A). Their relative position is greatly altered by the appearance of a number of flexures. These are:

- The ***cervical flexure***, at the junction of the rhombencephalon and the spinal cord (Figure 4.7B)
- The ***mesencephalic flexure*** (or ***cephalic flexure***) in the region of the midbrain (Figure 4.7C)

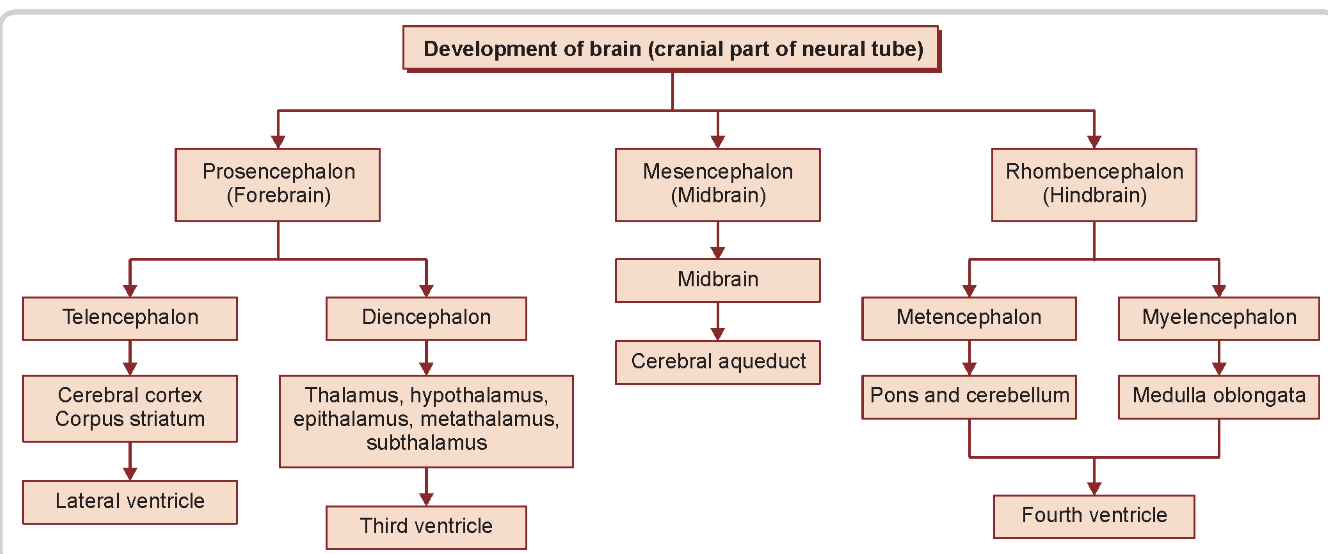


Figure 4.6: Development of various parts of brain from neural tube along with their cavities

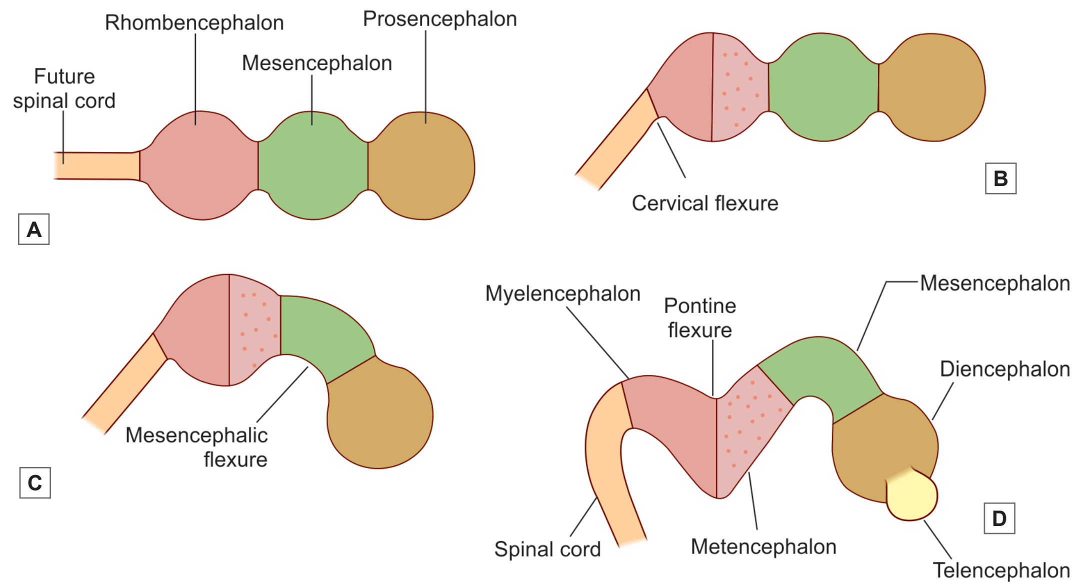


Figure 4.7: (**A**) Neural tube before formation of flexures (**B**) Cervical flexure formed (**C**) Mesencephalic flexure formed (**D**) Pontine flexure formed

- The ***pontine flexure***, at the middle of the rhombencephalon, dividing it into the metencephalon and myelencephalon (Figure 4.7D)
- The ***telencephalic flexure*** that occurs much later between the telencephalon and diencephalon.

These flexures lead to the orientation of the various parts of the brain as in the adult.

DEVELOPMENT OF VENTRICULAR SYSTEM

Each of the subdivisions of the developing brain encloses a part of the original cavity of the neural tube (Figure 4.8).

- The cavity of each telencephalic vesicle becomes the ***lateral ventricle***
- The cavity of diencephalon (along with the central part of the telencephalon) becomes the ***third ventricle***.

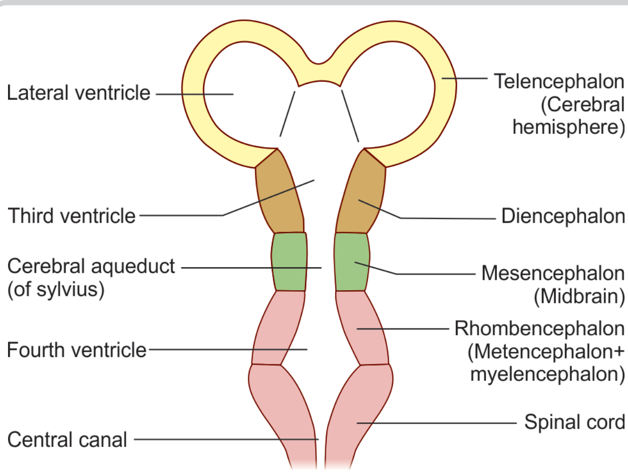


Figure 4.8: Development of ventricles of the brain

- The cavity of the mesencephalon remains narrow, and forms the ***cerebral aqueduct*** (aqueduct of Sylvius).
- The cavity of the rhombencephalon forms the ***fourth ventricle***. Its continuation in the spinal cord is the ***central canal***.

FORMATION OF NEURONS AND NEUROGLIAL CELLS

The neurons and many neuroglial cells are formed in the neural tube.

The neural tube is at first lined by a single layer of cells (Figure 4.9A). These proliferate to form several layers (Figures 4.9B and C).

- Nearest to the lumen of the tube is the ***matrix cell layer*** (also called primitive ependymal or germinal layer). The cells of this layer give rise to nerve cells, neuroglial cells, and also to more germinal cells.
- The next layer is the ***mantle layer*** in which the developing nerve cells and neuroglial cells are present.
- The outermost layer, termed the ***marginal layer***, contains no nerve cells. It consists of a reticulum formed by protoplasmic processes of developing neuroglial cells (***spongioblasts***). It provides a framework into which the processes of nerve cells developing in the mantle layer can grow and lay down the tracts.

Note: The wall of the neural tube consists of only one layer of elongated cells. The multilayered appearance is produced by nuclei being placed at different levels as in a pseudostratified epithelium.

Stages in the Formation of a Nerve Cell

- One of the germinal cells passes from the germinal layer to the mantle layer and becomes an ***apolar neuroblast*** (Figure 4.10A).

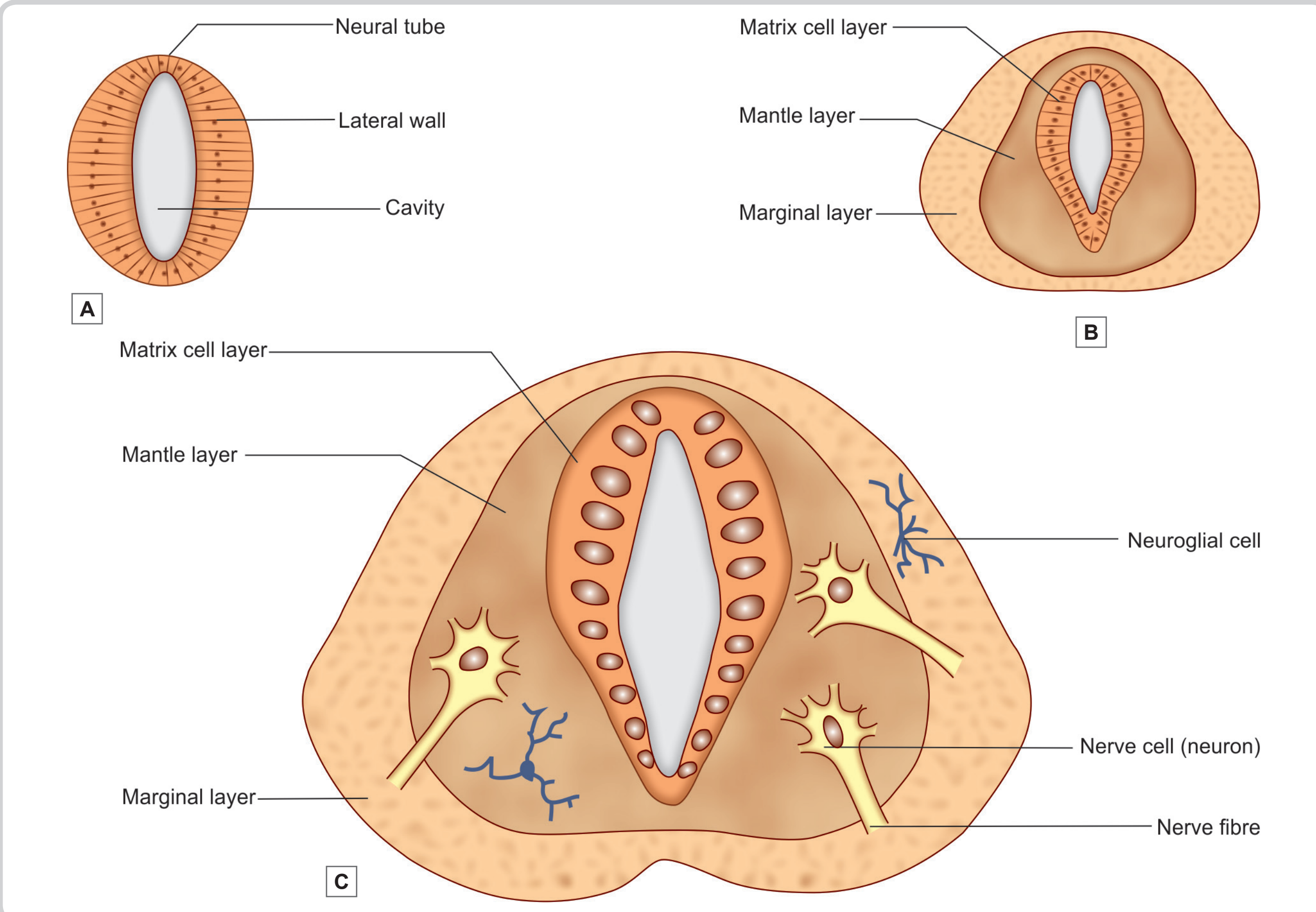


Figure 4.9: Layers of the neural tube (the epithelium appears to be multilayered, but it is actually pseudostratified)

- Two processes develop and convert the apolar neuroblast to a ***bipolar neuroblast*** (Figure 4.10B).
- One of the processes of the neuroblast disappears, and is called a ***unipolar neuroblast*** (Figure 4.10C).
- The process of the cell that does not disappear elongates, and on the side opposite to it, numerous smaller processes form. At this stage, the cell is called a ***multipolar neuroblast*** (Figure 4.10D). The main process of the multipolar neuroblast grows into the marginal layer and become the ***axon*** of the nerve cell (Figure 4.10D).

  The axon can grow to a considerable length. It may either remain within the central nervous system (CNS), or may grow out of it as an efferent nerve fibre of a peripheral nerve. At its destination, it establishes connections, either with the cell bodies and dendrites of other neurons or with an effector organ (e.g. muscle)
- The smaller processes of the neuroblast are the ***dendrites***. These ramify and establish connections with other nerve cells.
- At first, the cytoplasm of the nerve cell is homogeneous. Later, ***Nissl's granules*** make their appearance. After their formation, neurons lose the ability to divide.

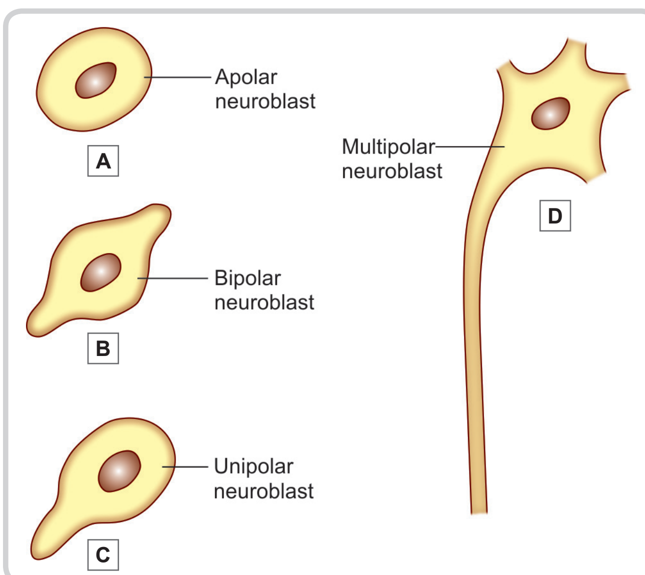


Figure 4.10: Stages in formation of a typical neuroblast

Stages in the Formation of Neuroglial Cells

Neuroglial cells are also formed from germinal cells of the ependymal layer. These cells (***glioblasts***) migrate to

the mantle and marginal zones as ***medulloblasts*** (also called ***spongioblasts***), which differentiate either into ***astroblasts*** and subsequently, into ***astrocytes***, or into ***oligodendroblasts*** and then, into ***oligodendrocytes***.

The ***microglial cells*** do not develop from the cells of the neural tube but migrate into it along with blood vessels. These cells are of mesodermal origin.

The ***ependymal (or neuroepithelial) cells*** give rise both to neuroblasts and to neuroglia. However, these two cell types are not formed simultaneously. The neuroblasts are formed first. Neuroglial cells are formed after the differentiation of neuroblasts is completed.

The formation of the myelin sheath by Schwann cells and oligodendrocytes has already been explained. Nerve fibres in different parts of the brain and spinal cord become myelinated at different stages of development. The process begins during the fourth month of intrauterine life, but is not completed until the child is 2–3 years old. Nerve fibres become fully functional only after they have acquired their myelin sheaths.

The blood vessels of the brain and their surrounding connective tissue are not derived from the neural tube. These are mesodermal in origin and invade the developing brain and spinal cord from the surrounding mesoderm.

The development of the ***pia mater*** and the ***arachnoid mater*** (***leptomeninges***) is not definitely understood. According to some workers, these are derived from the neural crest. The ***dura mater*** develops from the mesoderm surrounding the neural tube.

DEVELOPMENT OF SPINAL CORD

The spinal cord is developed from the caudal cylindrical part of the neural tube.

When this part of the neural tube is first formed, its cavity is in the form of a dorsoventral cleft. The lateral walls are thick, but the roof (dorsal) and the floor (ventral) are thin (Figure 4.11A). The wall of the tube subdivides into the matrix cell or ependymal layer, the mantle layer, and the marginal layer (Figure 4.11B), as already described.

The mantle zone grows faster in the ventral part of the neural tube and becomes thicker than in the dorsal part. As a result, the ventral part of the lumen of the neural tube becomes compressed. The line separating the compressed ventral part from the dorsal part is called the ***sulcus limitans*** (Figure 4.11C).

With its formation, the lateral wall of the developing spinal cord can be divided into a dorsal part, called the dorsal or ***alar lamina*** and a ventral part, called the ventral or ***basal lamina***. This division is of considerable functional importance. The basal lamina develops into structures that are motor in function, and the alar lamina into those that are sensory. The alar and basal laminae are also called the ***alar*** and ***basal plates***, respectively.

With continued growth in thickness of the mantle layer, the spinal cord gradually acquires its definitive form (Figure 4.11D and E). With growth of the alar lamina, the dorsal part of the cavity within the cord becomes obliterated. The posterior median septum is formed in this situation. The ventral part of the cavity remains as the ***central canal.*** Further enlargement of the basal lamina causes it to project forwards on either side of the midline, leaving a furrow, the ***anterior median fissure***, between the projecting basal laminae of the two sides.

The nerve cells that develop in the mantle zone of the basal lamina become the ***neurons of the anterior grey column*** (Figure 4.12). The axons of these cells grow out of the ventrolateral angle of the spinal cord to form the ***anterior nerve roots*** of the spinal nerves.

The nerve cells that develop in the mantle layer of the alar lamina form the ***neurons of the posterior grey column***. These are sensory neurons of the second order. Their axons travel predominantly upward in the marginal layer to form the ***ascending tracts*** of the spinal cord. Many of these cells form ***interneurons.***

The ***dorsal nerve roots*** are formed by the axons of cells that develop from the neural crest (Figure 4.12). Groups of these cells collect on the dorsolateral aspect of the developing spinal cord to form the ***dorsal nerve root ganglia*** (or ***spinal ganglia***). The axons of these cells divide into two. The central processes migrate toward the spinal cord and establish contact with the dorsolateral aspect of the latter, thus forming the ***dorsal nerve roots***. These axons finally synapse with neurons of the posterior grey column developing in the alar lamina. The peripheral processes of the cells of the dorsal nerve root ganglia grow outward to form the sensory components of the spinal nerves and end on the receptor.

As stated above, the axons of neurons in the posterior grey column enter the marginal layer, to form the ***ascending tracts*** of the spinal cord. At the same time, axons of cells developing in various parts of the brain grow downwards to enter the marginal layer of the spinal cord and form its ***descending tracts.*** These ascending and descending tracts form the ***white matter*** of the spinal cord. As the mantle layer takes on the shape of the anterior and posterior ***grey columns,*** the white matter becomes subdivided into anterior, lateral, and posterior ***white columns.***

DEVELOPMENT OF HINDBRAIN

Development of Medulla Oblongata

The medulla oblongata develops from the caudal part of rhombencephalic vesicle, i.e. myelencephalon. The early development of the medulla is similar to that of the spinal cord. The appearance of the sulcus limitans divides each lateral wall into a dorsal or alar lamina and a ventral or

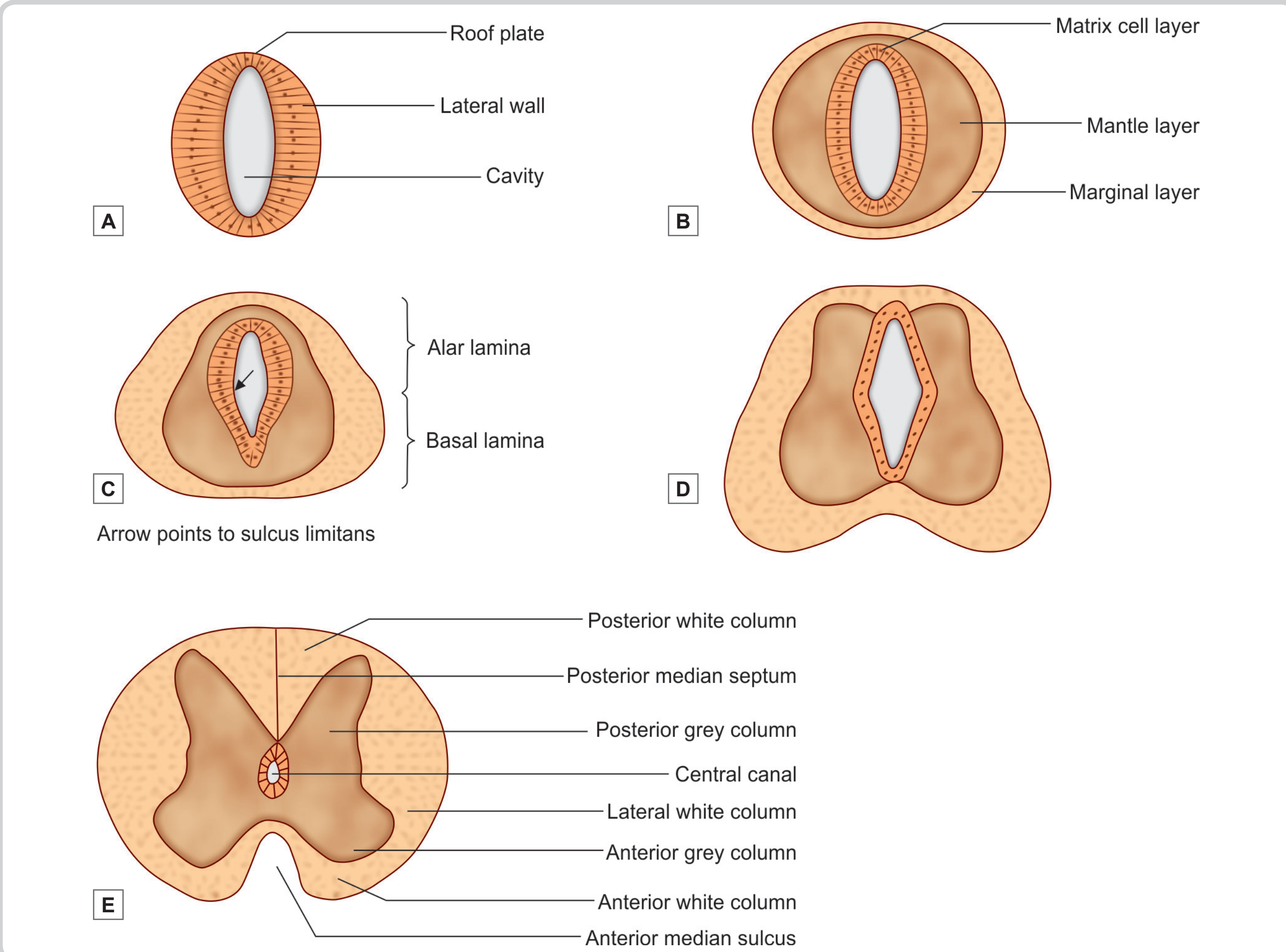


Figure 4.11: Schematic diagram to show stages in the development of the spinal cord

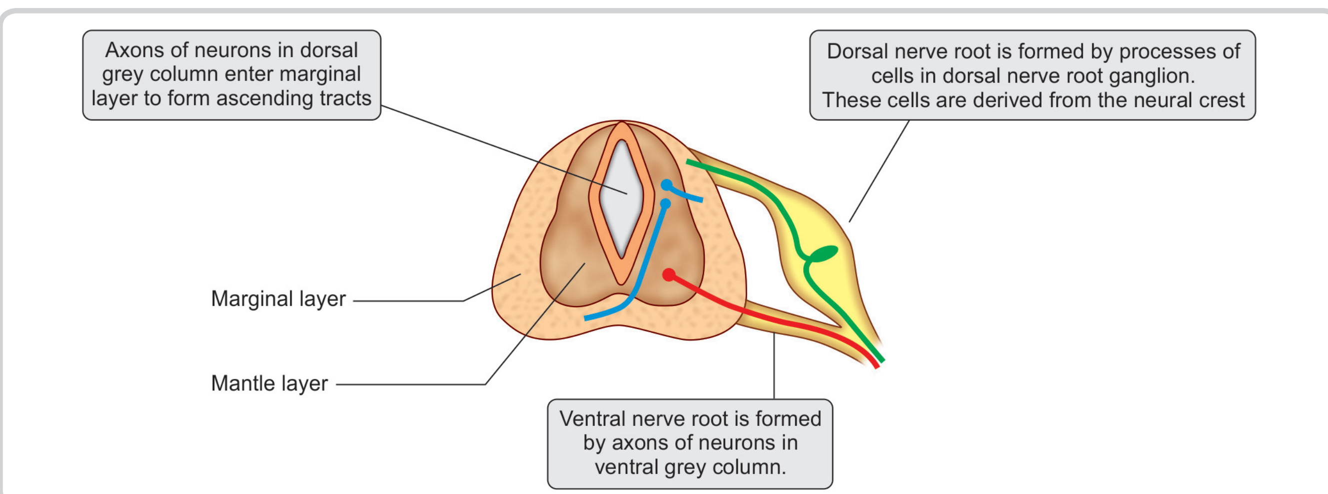


Figure 4.12: Development of spinal nerve roots

basal lamina. Subsequently, the thin ***roof plate*** becomes greatly widened as a result of which the alar laminae come to lie dorsolaterally to the basal laminae. Thus, both these laminae are now in the floor of the developing fourth ventricle (Figure 4.13).

Cells developing in the lateral part of each alar lamina migrate ventrally and reach the marginal layer overlying the ventrolateral aspect of the basal lamina. These cells constitute the caudal part of the ***bulbopontine extension*** and develop into the ***olivary nuclei***.

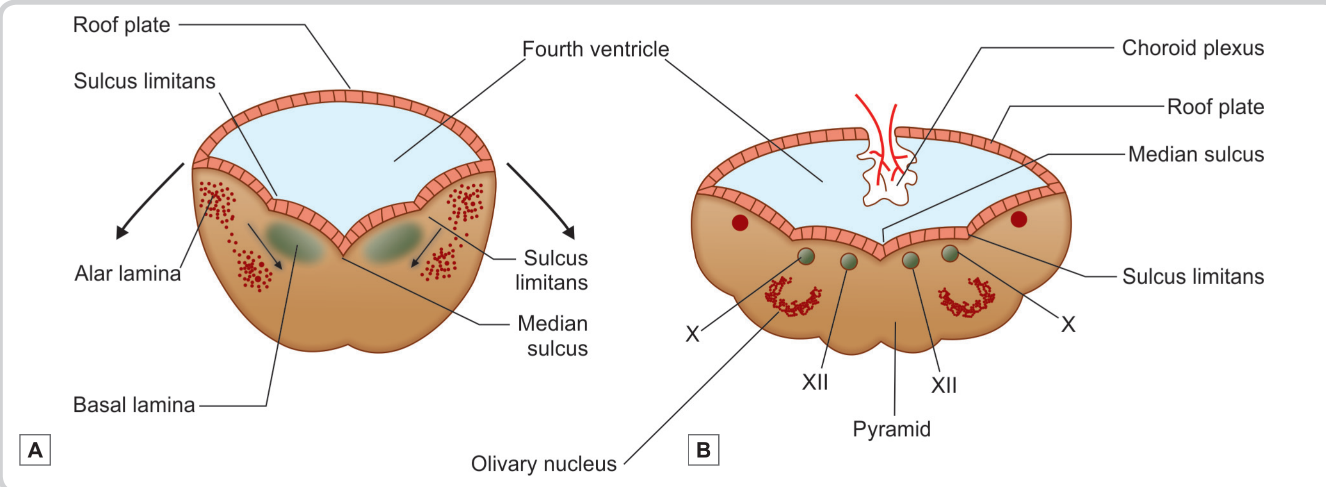


Figure 4.13: Schematic diagram to show stages in the development of the medulla oblongata (myelencephalon)

The remaining cells of the alar lamina develop into the sensory nuclei of the cranial nerves related to the medulla, i.e. of cranial nerves V, VIII, IX, and X.

The motor nuclei that are derived from the basal lamina are of nerves IX, X, XI, and XII.

The ***gracile and cuneate nuclei*** are derived from the lowermost part of the somatic afferent column.

The ***white matter*** of the medulla is predominantly extraneous in origin, being composed of fibres constituting the ascending and descending tracts that pass through the medulla.

Development of Pons

The pons arises from the ventral part of the metencephalon.

It also receives a contribution from the alar lamina of the myelencephalon, in the form of the cranial part of the bulbopontine extension. This extension comes to lie ventral to the metencephalon and gives rise to the ***pontine nuclei*** (Figure 4.14). Axons of cells in these nuclei, grow transversally to form the middle cerebellar peduncle.

As in the myelencephalon, the roof of the metencephalon becomes thin and broad. The alar and basal laminae are, thus, orientated as in the medulla.

The lateral part of each alar lamina (often called the ***rhombic lip***) of metencephalon becomes specialized to form the cerebellum. The ventral part of the alar lamina gives origin to the sensory nucleus of cranial nerves V and VII and the vestibular and cochlear nuclei of cranial nerve VIII and the basal lamina to the motor nuclei of cranial nerves V, VI, and VII.

The nuclei derived from the basal and alar laminae lie in the dorsal or tegmental part of the pons. The ventral part of the pons is constituted by:

- Cells of the bulbopontine extension (derived from the alar lamina of the myelencephalon) which form the pontine nuclei. Axons of the cells in these nuclei grow transversely and form the ***middle cerebellar peduncle***.
- Corticospinal and corticobulbar fibres that descend from the cerebral cortex and pass through this region on their way to the medulla and spinal cord. Some fibres from the cerebral cortex terminate in relation to the pontine nuclei. These are the corticopontine fibres.

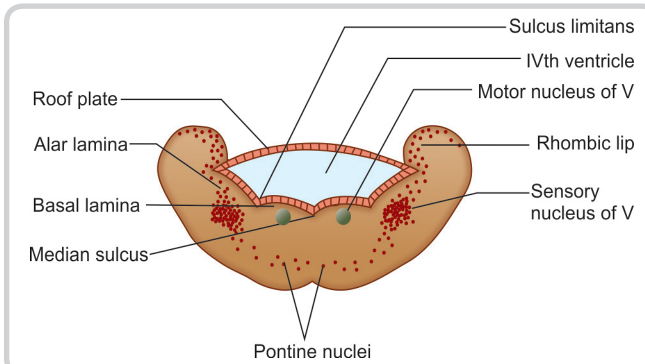


Figure 4.14: Development of the pons from the anterior part of the metencephalon

Development of Cerebellum

The cerebellum develops from the dorsolateral part of the alar lamina of the metencephalon (Figure 4.15A). There are at first two primordia of the cerebellum, right and left. These extend medially in the roof plate of the metencephalon to eventually fuse across the midline (Figure 4.15B and C). As the cerebellum increases in size, fissures appear on its surface. The lateral lobes and vermis can soon be distinguished, as a result of differential growth. The developing cerebellum can be divided into:

- An ***intraventricular part*** that bulges into the cavity of the developing fourth ventricle
- An ***extraventricular part*** that is seen as a bulge on the surface (Figure 4.15C)

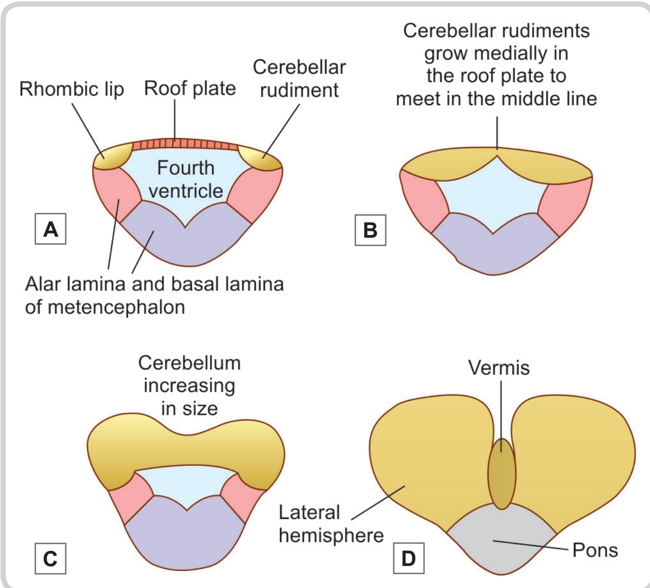


Figure 4.15: Schematic diagram to show some stages in the development of the cerebellum. (**A**) Cerebellar rudiments appear from alar lamina of metencephalon. (**B**) They grow into the roof plate of the metencephalon to meet in the midline. (**C**) Cerebellum enlarges and bulges out of the fourth ventricle. (**D**) Lateral hemispheres and vermis can be distinguished

At first, the intraventricular part is the larger of the two, but at a later stage, the extraventricular part becomes much larger than the intraventricular part and constitutes almost the whole of the organ (Figure 4.15D).

The cerebellum, at first, consists of the matrix, mantle, and marginal layers. Some cells of the mantle layer migrate into the marginal layer to form the cerebellar cortex. The cells of the mantle layer that do not migrate into the cortex develop into the ***dentate, emboliform, globose,*** and ***fastigial nuclei***.

The ***superior cerebellar peduncle*** is formed chiefly by the axons growing out of the dentate nucleus. The ***middle cerebellar peduncle*** is formed by axons growing into the cerebellum from the cells of the pontine nuclei. The ***inferior cerebellar peduncle*** is formed by fibres that grow into the cerebellum from the spinal cord and medulla.

DEVELOPMENT OF MIDBRAIN

The midbrain develops from the mesencephalon. The cavity of the mesencephalon remains narrow and forms the aqueduct.

As described in the case of the spinal cord, the mantle layer becomes subdivided into a dorsal or alar lamina and a ventral or basal lamina by the appearance of the sulcus limitans.

The nuclei which develop from the basal lamina are:
- The oculomotor nerve nucleus
- The trochlear nerve nucleus
- The Edinger–Westphal nucleus (GVE)

The alar lamina gives rise to the cells of the colliculi. At first, these form one mass, which later becomes subdivided by a transverse fissure. Some cells of the alar lamina migrate ventrally to form the ***red nucleus*** and the ***substantia nigra***.

The marginal layer of the ventral part of the mesencephalon is invaded by downward growing fibres of the corticospinal, corticobulbar, and corticopontine pathways. This region, thus, becomes greatly expanded, and forms the ***basis pedunculi*** (crus cerebri).

DEVELOPMENT OF FOREBRAIN

Development of Diencephalon

The diencephalon develops from the median portion of prosencephalon (Figure 4.16). Its cavity is called third ventricle.

As the telencephalic vesicles enlarge, it results in the diencephalon to lie on the medial side of the cerebral hemisphere.

The lateral wall of the diencephalon is subdivided by the appearance of the epithalamic and hypothalamic sulci. The central part lying between the two sulci enlarges to form the dorsal thalamus.

The part above the epithalamic sulcus remains small and forms the epithalamus, which is represented by the habenular nuclei and the pineal body.

The part below the hypothalamic sulcus forms the hypothalamus.

From the floor of the diencephalon, a diverticulum grows caudally dorsal to the Rathke's pouch, forming neurohypophysis. Adenohypophysis is derived from Rathke's pouch, that is an ectodermal diverticulum from the roof of the stomatodeum.

Two optic vesicles evaginate from the diencephalon, and each forms an optic cup and remains connected to the brain by the optic stalk. The optic cup develops into the retina, and the optic stalk becomes the optic nerve.

Development of Cerebral Hemisphere (Telencephalon)

The layout of structures in the cerebral hemisphere is better understood by the knowledge of its development (Figure 4.16).

The cerebrum is a derivative of the prosencephalon. The prosencephalon is divided into a median ***diencephalon*** and two lateral ***telencephalic vesicles*** (Figures 4.5 and 4.8). The telencephalic vesicles give origin, on either side, to the ***cerebral cortex*** and the ***corpus striatum***. The diencephalon gives rise to the ***thalamus***, ***hypothalamus,*** and related structures.

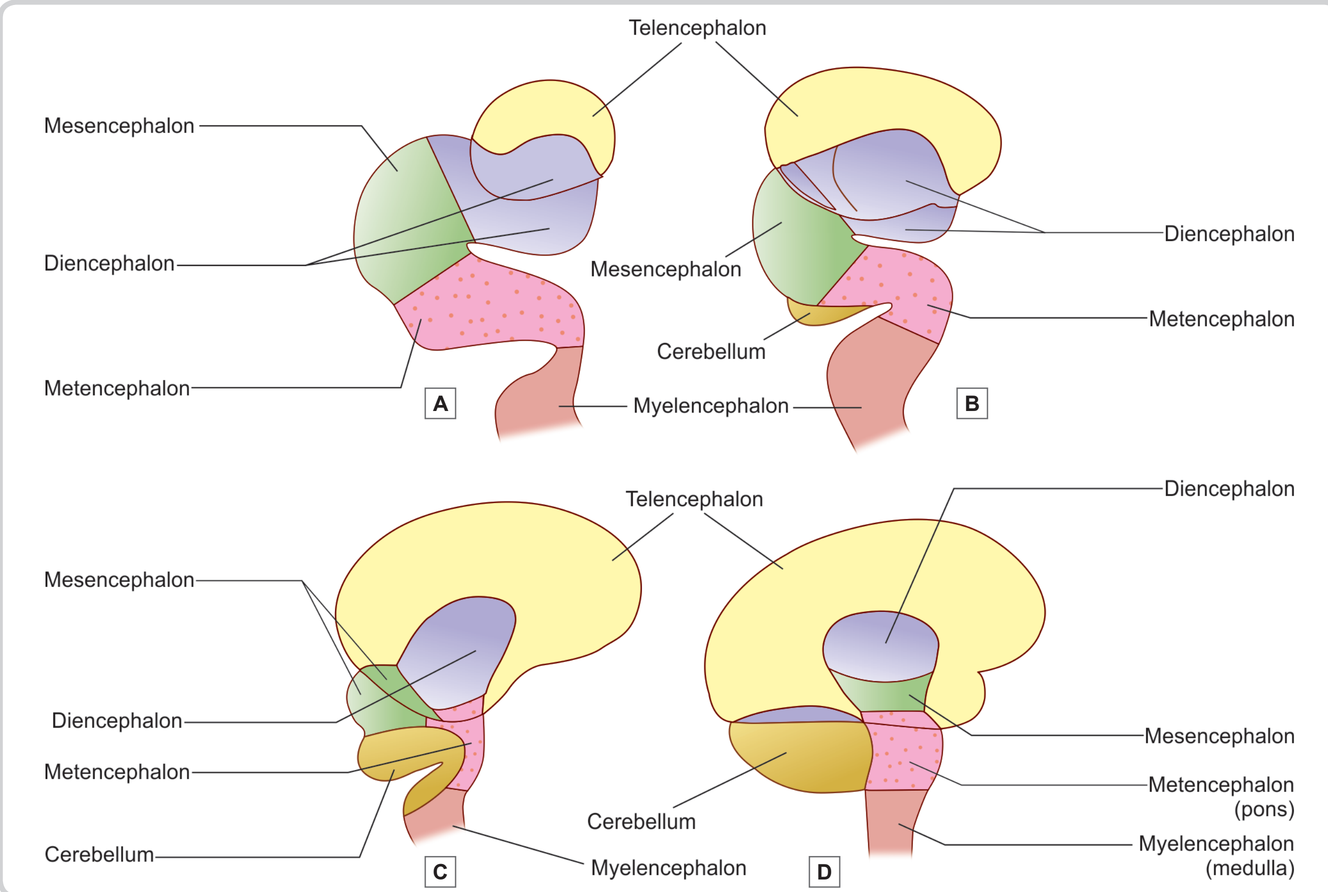


Figure 4.16: Development of external form of the human brain. Note the progressive overlap of diencephalon and mesencephalon by the expanding telencephalon

The telencephalic vesicles are, at first, small but rapidly increase in size extending upward, forward, and backward. As a result of this enlargement, the telencephalon comes to completely cover the lateral surface of the diencephalon and eventually fuses with it. Thus, the cerebral cortex and corpus striatum come to lie lateral to the thalamus and hypothalamus.

With further upward, forward, and backward extension of the telencephalic vesicles, the vesicles of the two sides come into apposition with each other above, in front of, and behind the diencephalon.

The cavity of the diencephalon forms the ***third ventricle***, while the cavities of the two telencephalic vesicles form the ***lateral ventricles***.

Each lateral ventricle is at first a spherical space within the telencephalic vesicle. With the forward and backward growth of the vesicle, the ventricle elongates anteroposteriorly. The posterior end of the telencephalic vesicle then grows downward and forward, to form the temporal lobe, and the cavity within it becomes the ***inferior horn***. The ventricle thus acquires a C-shape. Finally, as a result of backward growth, the occipital pole of the hemisphere is established, the part of the ventricle within it forms the ***posterior horn***.

Development of Corpus Striatum

The corpus striatum is a derivative of the thickened basal part of the telencephalon.

Nerve fibres of the developing internal capsule cut through the developing corpus striatum and divide it into medial and lateral parts. The medial part becomes the caudate nucleus. The lateral part forms the lentiform nucleus.

Clinical Correlation

Congenital Anomalies of the brain and the spinal cord

Nonclosure of neural tube

- **Posterior rachischisis:** The whole length of the neural tube remains unclosed (Figure 4.17A)
- **Anencephaly:** The neural tube remains open in the region of the brain because of nonclosure of the anterior neuropore. The exposed brain tissue degenerates.
  Note the following facts about anencephaly:
  - It is a serious defect incompatible with life
  - It can be diagnosed before birth by ultrasonography
  - The level of α-fetoprotein in amniotic fluid is raised
  - An anencephalic fetus cannot swallow amniotic fluid. This can lead to excessive amount of amniotic fluid (hydramnios).
- **Spina bifida:** Nonfusion of the neural tube can be associated with nonclosure of the cranium (***cranium bifidum***) or of the vertebral canal (***spina bifida***). As a result of nonfusion of the neural tube or of overlying bones (e.g. spina bifida), neural tissue may lie outside the cranial cavity or vertebral canal. When this happens in the region of the brain the condition is called ***encephalocele***, and when it occurs in the spinal region it is called ***myelocele*** (Figure 4.17B and C).

When the neural tube has closed and the outward bulge is the result of a defect in the overlying bones, the neural tissue is covered by bulging skin and membranes (***meningomyelocele***). The corresponding condition in the region of the skull is ***meningoencephalocele*** (Figure 4.17B,C and E). Occasionally, the protrusion is caused by the membranes alone (***meningocele***) with the neural tissue located normally (Figure 4.17D). Some varieties of these conditions are illustrated in Figures 4.17B to E. When a meningoencephalocele is present, the medulla oblongata and the tonsils of the cerebellum are displaced caudally into the foramen magnum and cause obstruction to the flow of cerebrospinal fluid. This leads to ***hydrocephalus***. These conditions together constitute the ***Arnold Chiari deformity***.

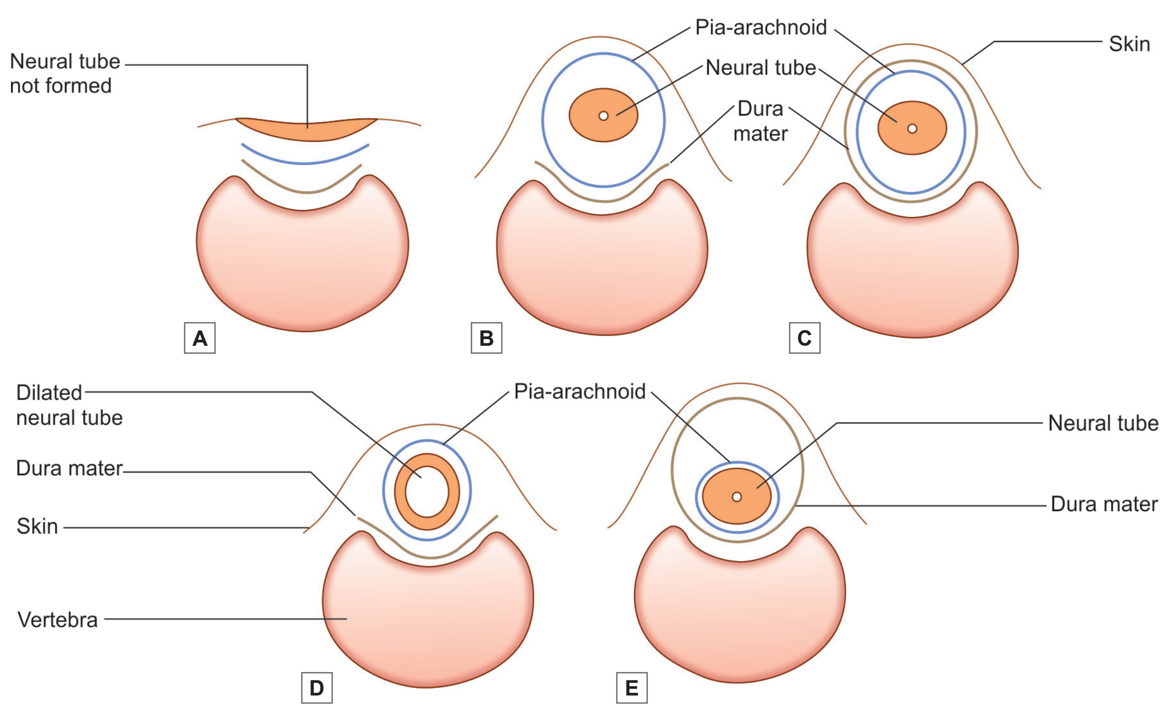


Figure 4.17: Anomalies of the neural tube (**A**) Posterior rachischisis (**B**) to (**D**) Varieties of meningomyelocele (**E**) Meningocele

Contd...

Congenital hydrocephalus

An abnormal quantity of cerebrospinal fluid may accumulate in the ventricular system of the brain (hydrocephalus). This may be due to a blockage to its flow or excessive production. The ventricles become very large and the infant is born with a large head. The pressure of the fluid causes degeneration of nervous tissue. Similar enlargement of the spinal cord is called hydromyelia; the enlargement of the central canal is syringocele. This condition may be associated with the formation of abnormal cavities near the central canal (syringomyelia). Destruction of nervous tissue at this site results in a characteristic syndrome.

In one form of hydrocephalus resulting from blockage of the median and lateral apertures of the fourth ventricle, the enlargement is predominantly in the posterior cranial fossa and the cerebellum is abnormal (***Dandy Walker syndrome***). Obstruction to the flow of cerebrospinal fluid may also be caused by stenosis or malformation of the cerebral aqueduct.

Faulty development

The brain may be too small (***microcephaly***) or too large (***macrocephaly***). Gyri may be absent or may be poorly formed (***lissencephaly***). Faulty development of the cerebral cortex may lead to impaired intelligence or in congenital paralysis.

Absence of parts of the nervous system

Parts of the nervous system may be absent. Absence of the corpus callosum, spinal cord, or cerebellum is documented.

Multiple Choice Questions

1. The cerebral aqueduct is developed from the cavity of
   A. Rhombencephalon
   B. Mesencephalon
   C. Telencephalon
   D. Diencephalon

2. The cranial end of the neural tube is represented by
   A. Anterior commissure
   B. Columns of fornix
   C. Lamina terminalis
   D. Interthalamic adhesion

3. The neurons of the grey column of the spinal cord originate from
   A. Marginal layer
   B. Neural crest cells
   C. Mantle layer
   D. Matrix layer

4. By which week of intrauterine life does the neural tube close?
   A. Fourth
   B. Fifth
   C. Sixth
   D. Seventh

5. The failure of closure of the cranial end of neural tube gives rise to
   A. Anencephaly
   B. Hydrocephalus
   C. Microcephaly
   D. Meningomyelocele

6. The cervical flexure of the neural tube occurs
   A. Between the forebrain and midbrain
   B. In the midbrain
   C. Between hindbrain and spinal cord
   D. In the hindbrain

Answers

1. B **2.** C **3.** C **4.** A **5.** A **6.** C

Chapter 5

Spinal Cord – External Features

Specific Learning Objectives

At the end of learning, the student shall be able to:

- Describe the external features of the spinal cord
- Define a spinal segment and correlate the spinal segmental level with the vertebral level
- Specify the segmental innervation of skin and spinal segments responsible for important movements
- Describe spinal reflexes and specify spinal segments responsible for important reflexes
- Describe the meninges covering the spinal cord and their specializations
- Specify the anatomical basis of lumbar puncture and epidural anesthesia
- Specify the blood supply of various parts of spinal cord

INTRODUCTION

The spinal cord or the spinal medulla is the most important content of the vertebral canal and in adults, it occupies only the upper two-thirds of the vertebral canal.

It begins as a downward extension of medulla oblongata at the level of the upper border of the first cervical vertebra (C1) and extends down to the level of the lower border of the first lumbar vertebra (L1) (Figure 5.1). Thus, it occupies the upper two-thirds of the vertebral column.The level is, however, variable and the cord may terminate one vertebra higher or lower than this level. The level also varies with flexion or extension of the spine.

The lowest part of the spinal cord is conical and is called the ***conus medullaris***. The conus is continuous, below, with a fibrous cord called the ***filum terminale*** (Figure 5.1), which is a prolongation of piamater and is attached to the posterior surface of the coccyx.

Dimensions of the Cord

The length of the cord varies from 42 to 45 cm. The spinal cord is not of uniform thickness. It resembles a flattened cylinder with variable transverse width i.e. about 38 mms at

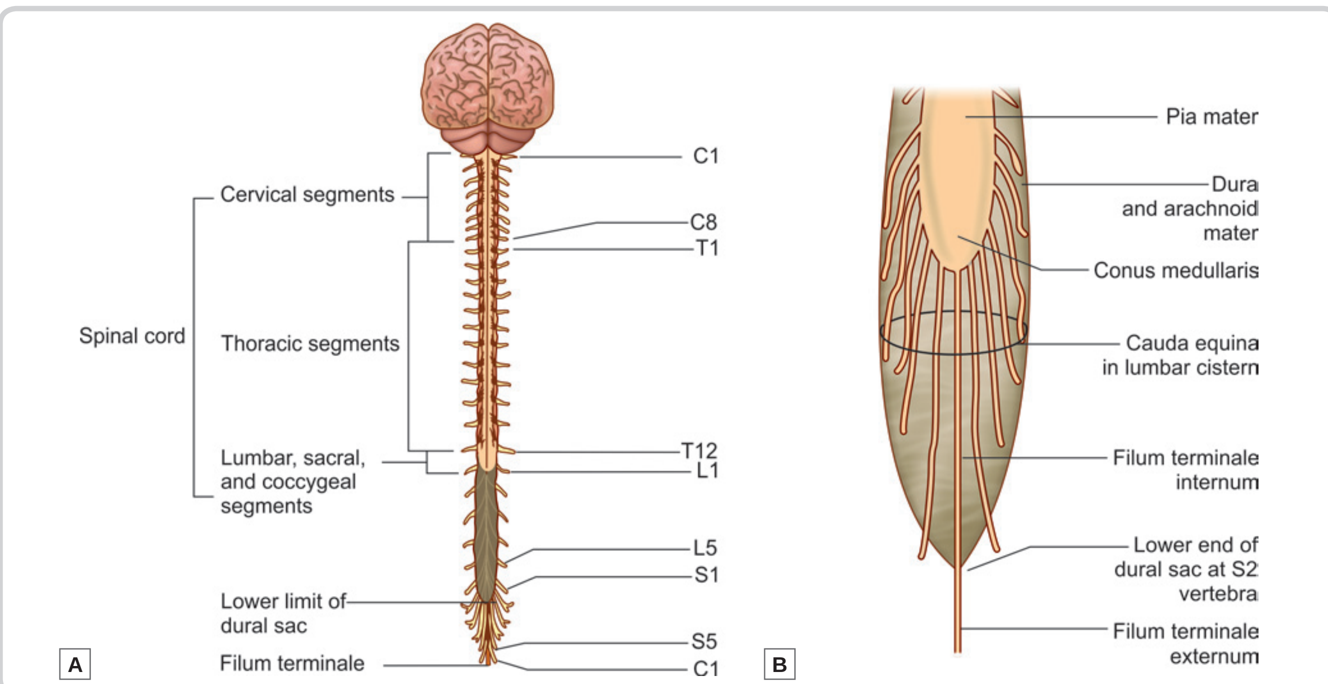


Figure 5.1: (**A**) The spinal cord (**B**) The lower end of spinal cord magnified showing the conus medullaris cauda equina and filum terminale

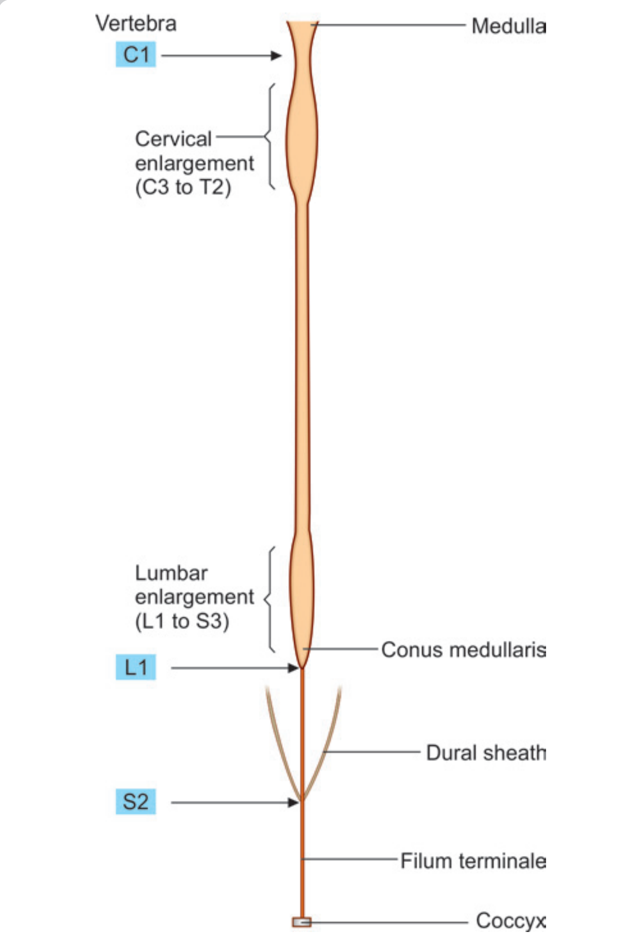


Figure 5.2: Important vertebral levels in relation to the spinal cord

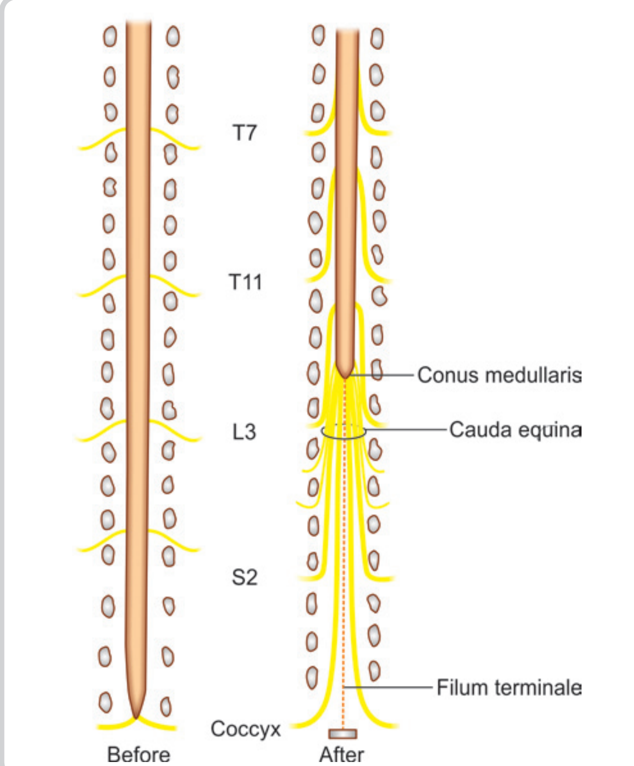


Figure 5.3: Scheme to show the effect of recession of the spinal cord (during development) on the course of the roots of spinal nerves

the cervical enlargement and about 35 mms at the lumbar enlargement. The spinal segments that contribute to the nerves of the upper limbs [from 3rd cervical to 2nd thoracic segments] are enlarged to form the ***cervical enlargement*** of the cord. Similarly, the segments innervating the lower limbs (1st lumbar to 3rd sacral segments) form the ***lumbar enlargement*** (Figure 5.2).

Age-wise Changes in the Cord

In early fetal life (third month), the spinal cord is as long as the vertebral canal and each spinal nerve arises from the cord at the level of the corresponding intervertebral foramen. In subsequent development, the spinal cord does not grow as much as the vertebral column, and its lower end, therefore, gradually ascends to reach the level of the third lumbar vertebra at the time of birth and to the lower border of the first lumbar vertebra in the adult.

As a result of this upward migration of the cord, the roots of spinal nerves have to follow an oblique downward course to reach the appropriate intervertebral foramen (Figure 5.3). This also makes the roots longer. The obliquity and length of the roots is most marked in the lower nerves and many of these roots occupy the vertebral canal below the level of the spinal cord. These roots constitute the ***cauda equina*** (Figures 5.1 and 5.3).

Functions of Spinal Cord

The spinal cord has three major functions:

- It acts as a pathway for motor information, which travels down the spinal cord.
- It serves as a conduit for sensory information in the reverse direction.
- It is a centre for coordinating simple reflexes.

SURFACE FEATURES OF SPINAL CORD

The anterior surface of the spinal cord is marked by a deep anterior median fissure, which contains anterior spinal artery (Figure 5.4A).

The posterior surface is marked by a shallow posterior median sulcus (Figure 5.4B).

The anterior median fissure and posterior median sulcus divide the surface of the cord into two symmetrical halves. Each half of the cord is further subdivided into posterior, lateral, and anterior regions by anterolateral and posterolateral sulci (Figures 5.4A and B).

The rootlets of the dorsal or sensory roots of spinal nerves enter the cord at the posterolateral sulcus on either side.

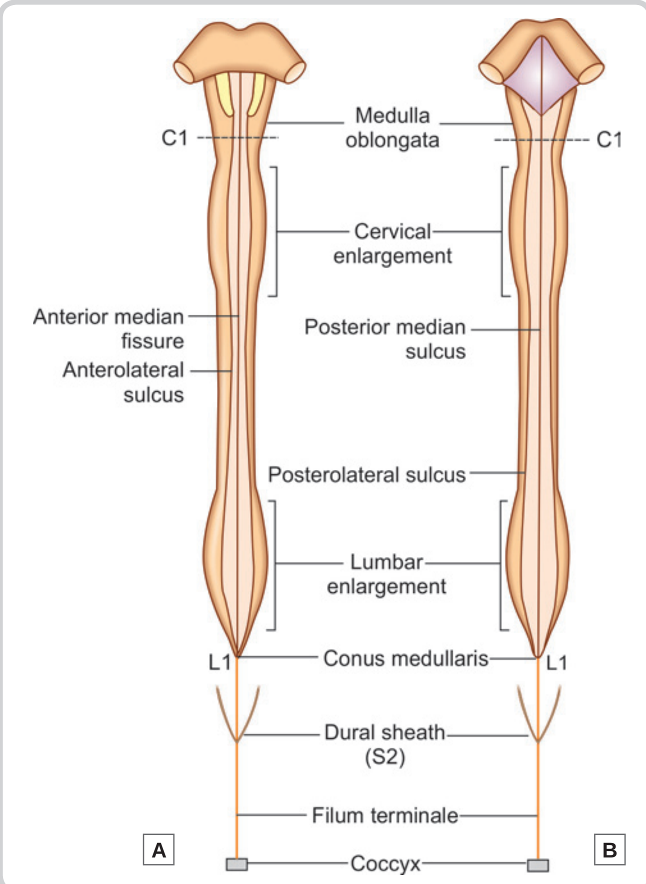


Figure 5.4: External features of the spinal cord (**A**) Anterior aspect (**B**) Posterior aspect

The rootlets of the ventral or motor roots of spinal nerves emerge through the anterolateral sulcus on either side.

SPINAL NERVES

The spinal cord gives attachment on either side to 31 pairs of spinal nerves: 8 cervical, 12 thoracic, 5 lumbar, 5 sacral, and 1 coccygeal.

Each spinal nerve arises by two roots, anterior motor root and posterior sensory root (Figures 5.5 and 5.6).

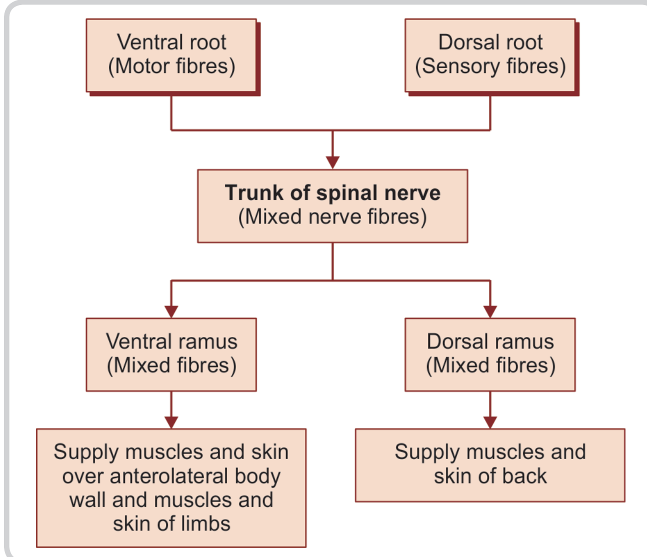


Figure 5.5: Flow diagram showing formation of a spinal nerve

Each root is formed by aggregation of a number of rootlets that arise from the cord over a certain length (Figure 5.7).

The rootlets that make up the dorsal nerve roots are attached to the surface of the spinal cord along a vertical groove (called the ***posterolateral sulcus***) opposite the tip of the posterior grey column. The rootlets of the ventral nerve roots are attached to the anterolateral sulcus of the cord opposite the anterior grey column.

Both the roots of spinal nerve receive a tubular prolongation from the spinal meninges and enter the corresponding intervertebral foramen.

In the intervertebral foramen, anterior and posterior spinal nerve roots unite to form the mixed spinal nerve trunk. Thus, a spinal nerve is made up of a mixture of motor and sensory fibres.

Just proximal to the junction of the two roots, the dorsal root is marked by a swelling called the ***dorsal nerve root ganglion*** or ***spinal ganglion*** (Figure 5.6).

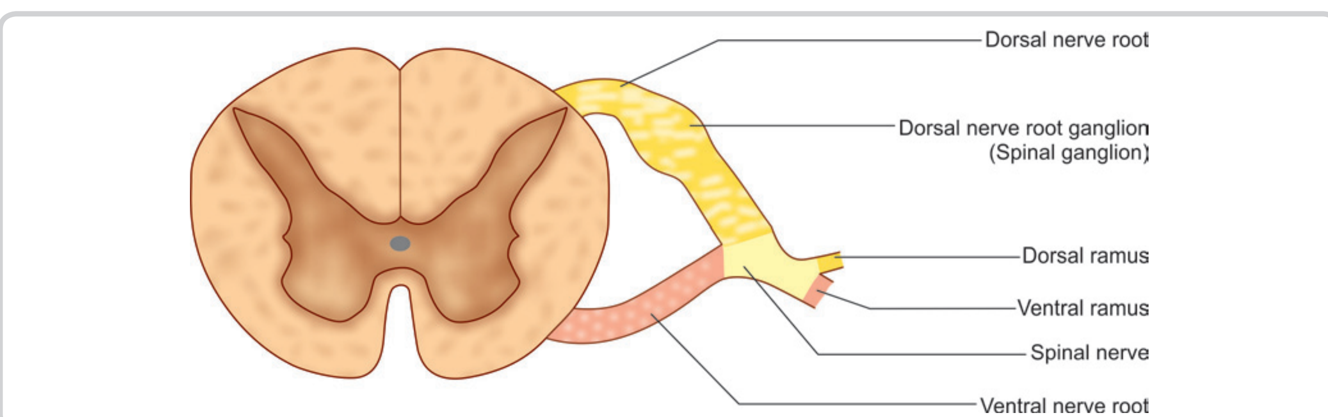


Figure 5.6: Relationship of a spinal nerve to the spinal cord

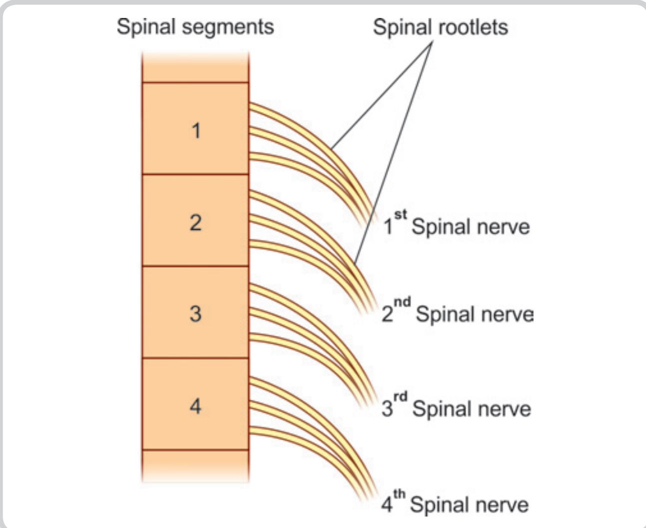


Figure 5.7: Scheme to show the concept of spinal segments

The rootlets of dorsal root are made up of the central processes of neurons of the dorsal root ganglion. The dorsal root itself contains peripheral processes of neurons of the dorsal root ganglion.

After emerging from the intervertebral foramen, each spinal nerve is divided into a dorsal and a ventral rami (Figures 5.5 and 5.6).

The dorsal ramus passes posteriorly around the vertebral column to supply the muscles and skin of the back. The ventral ramus continues anteriorly to supply the muscles and skin over the anterolateral body wall and all the muscles and skin of the limbs.

Clinical Correlation

The dorsal nerve root ganglia (and the sensory ganglia of cranial nerves) can be infected with a virus. This leads to the condition called ***herpes zoster***. Vesicles appear on the skin over the area of distribution of the nerve. The condition is highly painful.

SPINAL SEGMENTS

As mentioned earlier, each spinal nerve arises from the spinal cord by two roots—anterior (or ventral) and posterior (or dorsal). Each nerve root is formed by an aggregation of a number of rootlets that arise from the cord over a certain length. The length of the spinal cord giving origin to the rootlets for one spinal nerve constitutes one spinal segment (Figure 5.7). However, this definition applies only to the superficial attachment of nerve roots. The neurons associated with one spinal nerve extend well beyond the confinement of a spinal segment. So, the spinal cord is made up of 31 such segments – 8 cervical, 12 thoracic, 5 lumbar, 5 sacral and 1 coccygeal.

Note: In the cervical and coccygeal regions, the number of spinal segments and spinal nerves, does not correspond to the number of vertebrae.

Vertebral levels of Spinal Segments

Since the length of spinal cord (45 cm) is smaller than that of vertebral column (65 cm), the spinal segments are short and crowded, more so in the lower part of the cord. Thus, the spinal and vertebral segments (spines) do not lie at the same level. ***The spinal segments as a rule always lie above their numerically corresponding vertebral spines***. As a rough guide, it may be stated that in the cervical region, there is a difference of one segment (for example, the fifth cervical spine overlies the sixth cervical segment); in the upper thoracic region, there is a difference of two segments (for example, the fourth thoracic spine overlies the sixth thoracic segment); and in the lower thoracic region, there is a difference of three segments (for example, the ninth thoracic spine lies opposite the twelfth thoracic segment). Approximate spinal segments and the corresponding vertebral level are shown in Table 5.1.

This is clinically important for assessing the level of cord compression following an injury or disease of the surrounding vertebrae.

Table 5.1 | Relation between vertebral levels and spinal segments

Vertebral Level	Formula-(To get the number of spinal segment underlying, add the numeral to the number of vertebra)	Example
Upper Cervical C1–C4	**Add 0** to the number of vertebra to get the underlying spinal segment	3rd cervical spine overlies the 3rd cervical segment
Lower Cervical C5–C7	**Add 1** to the number of vertebra to get the underlying spinal segment	5th cervical spine overlies the 6th cervical segment
Upper Thoracic T1–T6	**Add 2** to the number of vertebra to get the underlying spinal segment	4th thoracic spine overlies the 6th thoracic segment
Lower Thoracic T7–T9	**Add 3** to the number of vertebra to get the underlying spinal segment	9th thoracic spine overlies the 12th thoracic segment
T10	—	L1–L2 segments
T11	—	L3–L4 segments
T12	—	L5–S1 segments
L1	—	S2 to C0 segments

Exit of Spinal Nerves

Each spinal nerve emerges through the intervertebral foramen. The cervical nerves leave the vertebral canal above the corresponding vertebrae with the exception of eighth, which emerges between seventh cervical and first thoracic vertebrae. Rest of the spinal nerves emerge below the corresponding vertebrae.

SEGMENTAL INNERVATION

Any condition that leads to pressure on the spinal cord, or on spinal nerve roots, can give rise to symptoms in the region supplied by nerves. In such cases it is important to be able to localize the particular spinal segments or roots involved. For this purpose it is necessary to know which areas of skin and which muscles are innervated by each segment. Spinal segments responsible for myotatic reflexes also give an indication about the level of spinal cord involvement.

Dermatomes

Areas of skin supplied by individual spinal nerves are called ***dermatomes***. To understand the arrangement of dermatomes, it is necessary to know some facts about the development of the limbs.

The upper and lower limbs are derived from limb buds. These are paddle-shaped outgrowths that arise from the side-wall of the embryo. They are at first directed forward and laterally from the body of the embryo (Figure 5.8). Each bud has a ***preaxial (or cranial) border*** and a ***postaxial border*** (Figure 5.9). The thumb and great toe are formed on the preaxial border.

The forelimb bud is derived from the part of the body wall belonging to segments C4, C5, C6, C7, C8, T1 and T2. It is, therefore, innervated by the corresponding spinal nerves. The hindlimb bud is formed opposite the segments L2, L3, L4, L5, S1 and S2. As the limbs grow skin supplied by these nerves gets "pulled away" into the limbs. This has a great effect on the arrangement of dermatomes (Figures 5.10 and 5.11). The dermatomes of the body are shown in Figure 5.12.

The following ***facts about dermatomes*** are of clinical significance:

- Spinal nerve ***C1 does not supply any area of skin***

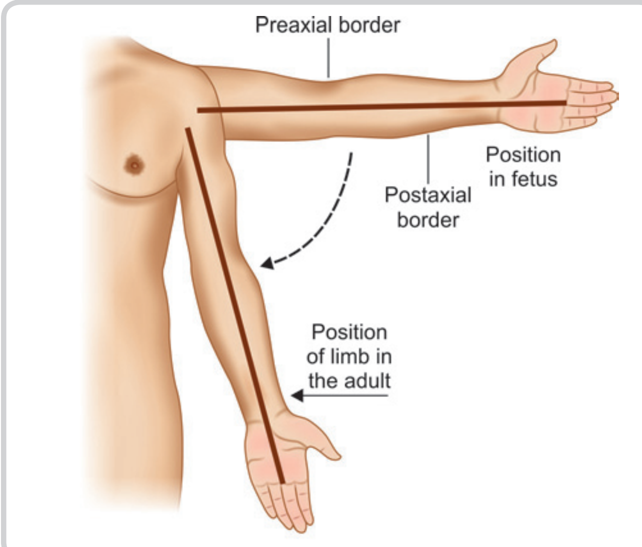


Figure 5.9: Scheme showing that with the external rotation of the embryonic limb, the preaxial border becomes the lateral border

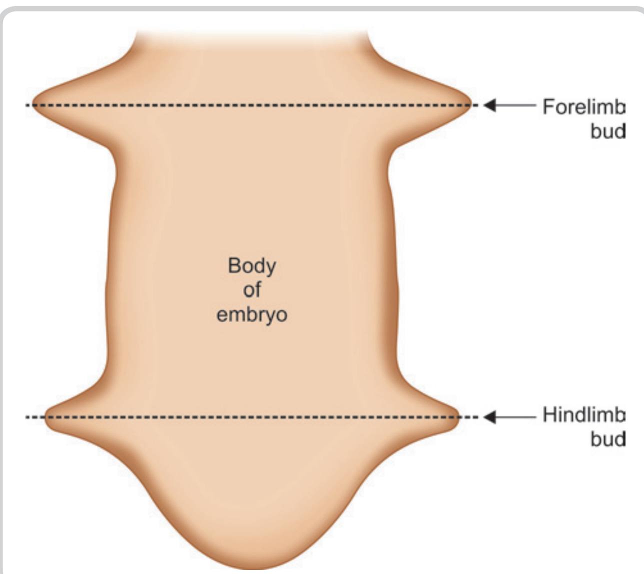


Figure 5.8: Scheme to show that the longitudinal axis of the limb buds is transverse to the long axis of the embryonic body

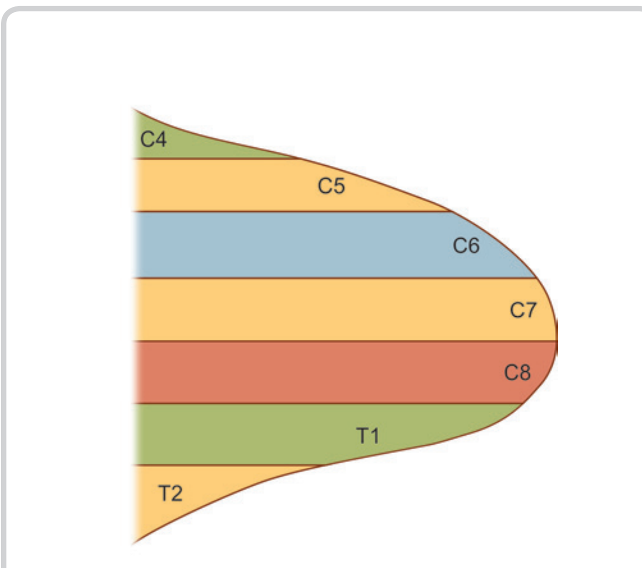


Figure 5.10: Dermatomes of the upper limb in an embryo

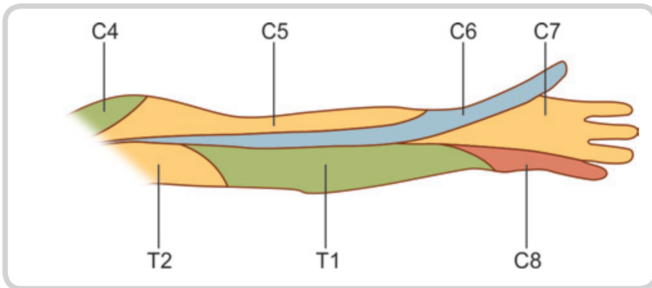


Figure 5.11: Dermatomes of the upper limb in an adult

- The areas supplied by different spinal nerves overlap in such a way that any given area is supplied by two (or more) nerves. The overlap is less for fibres carrying sensation of touch and more for those carrying pain and temperature. Hence, maps of dermatomes are only approximate.
- Because of what has been said above (about the development of the limbs) the lateral (preaxial) aspect of the upper limb is supplied (in sequence) by segments C4 to C6 and the medial aspect by segments C8 to T2. The segment C7 supplies an intermediate strip.
- The layout becomes complex in the lower limb because, during development, the lower limb bud rotates internally.
- As a rule, the arrangement of dermatomes is simple over the trunk, as successive horizontal strips of skin are supplied by each spinal nerve of the region. However, the arrangement is unusual over the pectoral region. The skin of the upper part of the pectoral region is supplied by spinal segments C3 and C4 (up to the level of the sternal angle). The area just below the level of the sternal angle is supplied by segment T2. This is so

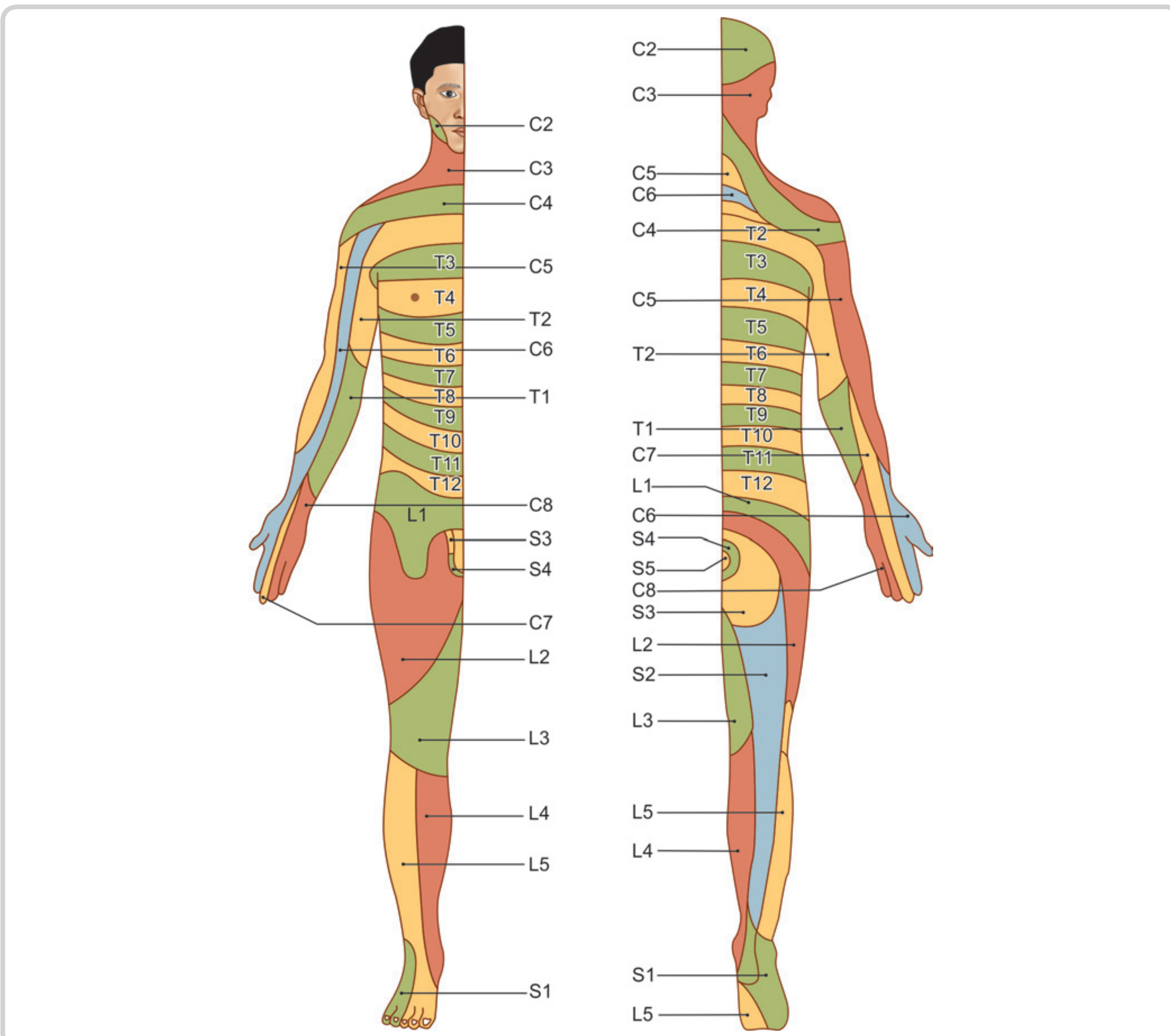


Figure 5.12: Dermatomes of the body on the front (left) and on the back (right)

because nerves C5 to T1 have been pulled away into the upper limb. For the same reason there is no overlap between the areas supplied by C4 and T2.

Segmental Innervation of Muscles

The nerve supply of muscles can also be described on the basis of spinal nerves from which the fibres are derived, i.e. in terms of spinal segments.

Table 5.2 | Segmental Innervation of Muscles Producing Various Movements

Movements	Spinal segments
Movements of the head	C1 to C4
Movements of the diaphragm (Injury above C3 causes paralysis of all respiratory muscles and death)	C3 to C5
Movements of the upper limb (Injury at C4–C5 level paralyses all four limbs—quadriplegia)	**C5 to T1**
Abduction and lateral rotation of shoulder	C5
Adduction and medial rotation of shoulder	C6, C7, C8
Flexion of elbow	C5, C6
Extension of elbow	C7, C8
Supination of forearm	C6
Pronation of forearm	C7, C8
Flexion of wrist	C6, C7
Extension of wrist	C6, C7
Movements of fingers	C7, C8, T1
Movements of lower limb (Injury above this level paralyses both the lower limbs—paraplegia)	**L1 to S3**
Flexion, adduction and medial rotation of hip	L1, L2, L3
Extension, abduction and lateral rotation of hip	L5, S1
Extension of knee	L3, L4
Flexion of knee	L5, S1
Dorsiflexion of ankle	L4, L5
Plantar flexion of ankle	S1, S2
Inversion of foot	L4, L5
Eversion of foot	L5, S1
Movements of toes	S2, S3
Filling of the urinary bladder	T12 to L2
Evacuation of urinary bladder	S2 to S4
Erection of the penis	S2 to S4
Ejaculation	L1 and L2—smooth muscle S2 and S4—striated muscle

- It is rare for a muscle to be supplied only by one segment. One example is innervation of intrinsic muscles of the hand.
- Most of the muscles derive innervation from two or more segments.
- The segments supplying muscles acting on a joint, supply the joint itself and also the skin over the joint (Hilton's law).
- Muscles having a common action are usually supplied by the same spinal segments.

The spinal segments supplying a muscle are often given differently in different books. This can be due to individual variations in the subjects studied, or due to different methods of investigation used. It is difficult to remember the segmental supply. A simplified presentation of the segments supplying the muscles of the upper limb and of the lower limb is given in Table 5.2. The integrity of spinal segments can also be tested by examining reflexes mediated by the segment.

SPINAL REFLEXES

Myotatic or Stretch Reflexes

Sudden stretching of a muscle (by tapping its tendon) produces reflex contraction of the muscle. The pathway for this reflex involves two neurons only. Stretching of the muscle stimulates proprioceptive nerve endings located in muscle spindles. These impulses are carried to the spinal cord by neurons that synapse with motor neurons in the

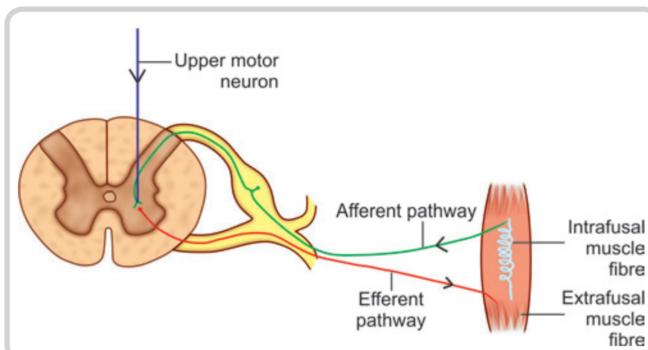


Figure 5.13: A spinal reflex arc showing pathway for stretch reflex or myotatic reflex

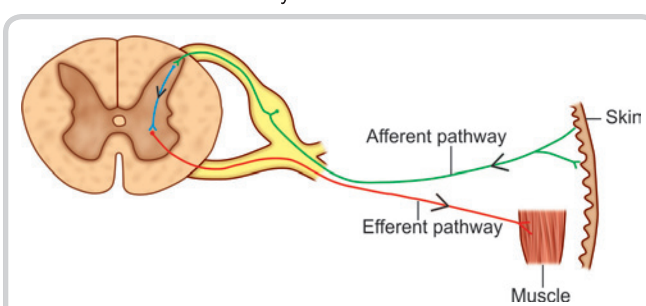


Figure 5.14: A spinal reflex arc showing pathway for superficial reflex

Table 5.3 | Spinal segments responsible for some of the reflexes

Reflex	Description	Spinal segments / Nerve responsible
Knee jerk or patellar tendon reflex	Extension of the leg by contraction of the quadriceps when the ligamentum patellae	L3, L4
Ankle jerk or Achilles tendon reflex	Plantar flexion of the foot on tapping the tendocalcaneus	S1, S2
Biceps tendon reflex	Flexion of the forearm on tapping the biceps tendon	C5, C6
Triceps tendon reflex	Extension of the forearm on tapping the triceps tendon	C7, C8
Supinator jerk (or radial periosteal reflex	Flexion of the forearm when the distal end of the radius is tapped (The muscle responsible for this reflex is the brachioradialis, not the supinator. It is called the supinator jerk because the brachioradialis was at one time called the supinator longus).	C6, C7
Wrist tendon reflex	Flexion of the fingers on percussion on wrist tendons	C8, T1
Abdominal reflexes: Upper Middle Lower	Contraction of underlying muscles on stroking the skin of the abdomen in its upper, middle, and lower parts	T7, 8 T9, 10 T11 to T12
Cremasteric reflex	Elevation of the scrotum on stroking the skin of the medial side of the thigh	L2
Gluteal reflex	Contraction of the glutei on stroking the overlying skin	L4 to S1
Plantar reflex	Plantar flexion and adduction of the toes on stroking the skin of the sole	L5 to S2
Anal reflex	Contraction of the external anal sphincter on stroking the perianal region	S4, 5, coccygeal

ventral grey columns (Figures 5.13 and 5.14). Fibres arising from these motor neurons reach the muscle and produce contraction. Stretch reflexes are abolished if any part of the pathway for it (i.e., the reflex arc) is interrupted. Stretch reflexes are exaggerated in upper motor neuron lesion. In contrast, superficial polysynaptic reflexes are abolished in corticospinal tract lesions and in lesions of spinal cord. From a clinical point of view it is important to know the level of the spinal cord at which each reflex is mediated. Some of the important reflexes are described in Table 5.3.

The normal ***plantar reflex*** consists of plantar flexion and adduction of the toes on stroking the skin of the sole (L5 to S2). When there is an injury to the corticospinal system, an abnormal response is obtained. There is extension (dorsiflexion) of the great toe and fanning out of other toes. This response is referred to as ***Babinski sign***. Such a response may also be seen in newborn infants and sometimes in sleeping or intoxicated adults. An extension of Babinski sign, in partial foot amputees, on stimulation of their amputated stump, shows dorsiflexion of ankle, flexion of knee and flexion of hip joints.

Jaw jerk or masseteric reflex is a myotatic reflex mediated through the trigeminal nerve (and not through the spinal cord). To elicit this reflex the patient is asked to open the mouth slightly. The examiner places his index finger over the middle of the patient's chin and taps it. This results in bilateral contraction of the masseter and temporalis muscles. Both afferent and efferent components of the reflex arc pass through the mandibular division of the trigeminal nerve, the nuclei concerned being located in the pons.

SPINAL MENINGES (Fig. 5.15)

Dura Mater

The spinal dura mater forms a loose tubular covering for the spinal cord. The spinal dura mater ***does not fuse with the endosteum*** of the vertebral canal. Hence there is a well-developed ***epidural space*** surrounding the spinal cord. The spinal epidural space is filled with the internal vertebral venous plexus (Batson's plexus) and fat.

Clinical Correlation

Epidural anesthesia

As the spinal nerves pass through the spinal epidural space, they may be anesthetized by injecting a local anaesthetic drug into the spinal epidural space. This type of epidural anesthesia is used in obstetric procedures during child birth. One has to be careful about the venous plexus while introducing the needle for anesthesia as it may injure the veins and cause an epidural hematoma.

Caudal epidural anesthesia

For this procedure, the needle is introduced through the sacral hiatus and the anesthetic drug is injected. This will anesthetize perineal area supplied by S4, S5 nerves and may be useful in perineal surgeries.

The dorsal and ventral roots of spinal nerves pass through the spinal dura mater separately. Sheaths derived from dura extend over the nerve roots. These dural sheaths reach up to the intervertebral foramina and are attached to the margins of these foramina. The dorsal and ventral nerve roots unite in the intervertebral foramina to form

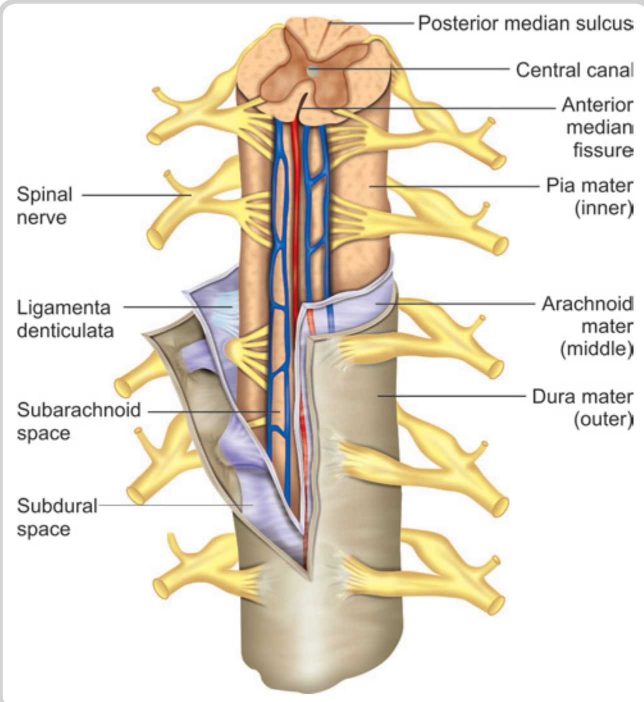


Figure 5.15: Spinal meninges

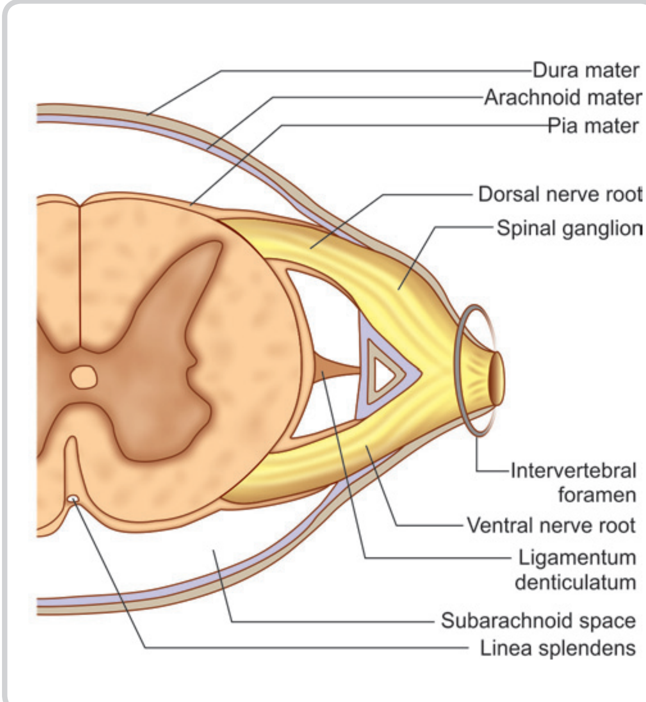


Figure 5.16: Transverse section through spinal cord to show the formation of meningeal sheaths over the roots of a spinal nerve

the trunks of spinal nerves. The pia mater and arachnoid mater also extend on to the roots of spinal nerves as sheaths. These sheaths reach up to the site where the nerve roots pass through dura mater (Figure 5.16).

The dura and arachnoid [along with the subarachnoid space containing cerebrospinal fluid (CSF)] extend up to the level of second sacral vertebra. Beyond that level, the dura covers the filum terminale and distally gets attached to the dorsal surface of the first coccyx vertebra. At the upper end of the vertebral canal, the dura fuses with the endosteum at foramen magnum. So the epidural space ends at that level and does not continue into the cranium even as the dura is continuous.

Arachnoid Mater

The spinal arachnoid mater is present deep to the dura and extends upto the level of second sacral vertebra. Above it is continuous with the cranial arachnoid mater and so also the subarachnoid space.

Pia Mater

The spinal pia mater is a thin vascular membrane closely applied to the spinal cord and specialized in some areas and continues above with the cranial pia mater.

- ***Linea splendens:*** Along the anteromedian fissure, the pia mater is thickened to form a glistening band called as ***linea splendens*** (Figure 5.16). The branches from the anterior spinal artery pierce this to enter the spinal cord.
- ***Ligamenta denticulata:*** Along the lateral aspect of spinal cord, between the dorsal and the ventral roots, the pia forms triangular thickenings which pierce the arachnoid and are attached to the dura. These tooth-like thickenings are called as ***ligamenta denticulata*** (Figures 5.15 and 5.17). There are 21/22 pairs of ligamenta denticulata.
- ***Filum terminale:*** At the lower end of the spinal cord, the pia mater extends as a thin filament surrounded by the leash of nerves (Figures 5.1 and 5.3). This is the filum terminale and it passes through the sacral hiatus and gets attached to the dorsal surface of the first coccygeal vertebra.

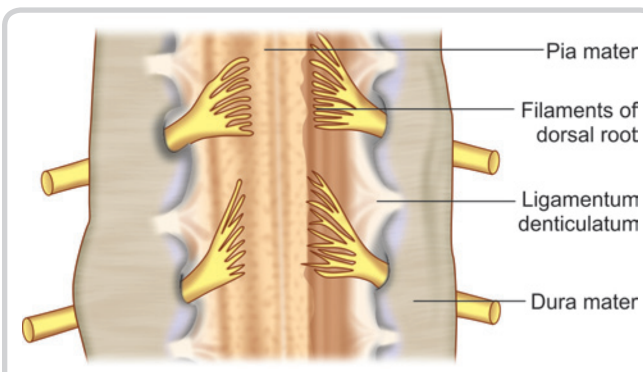


Figure 5.17: Spinal pia mater seen from posterior aspect
Note the extension of pia mater as ligamenta denticulata attached to the dura mater

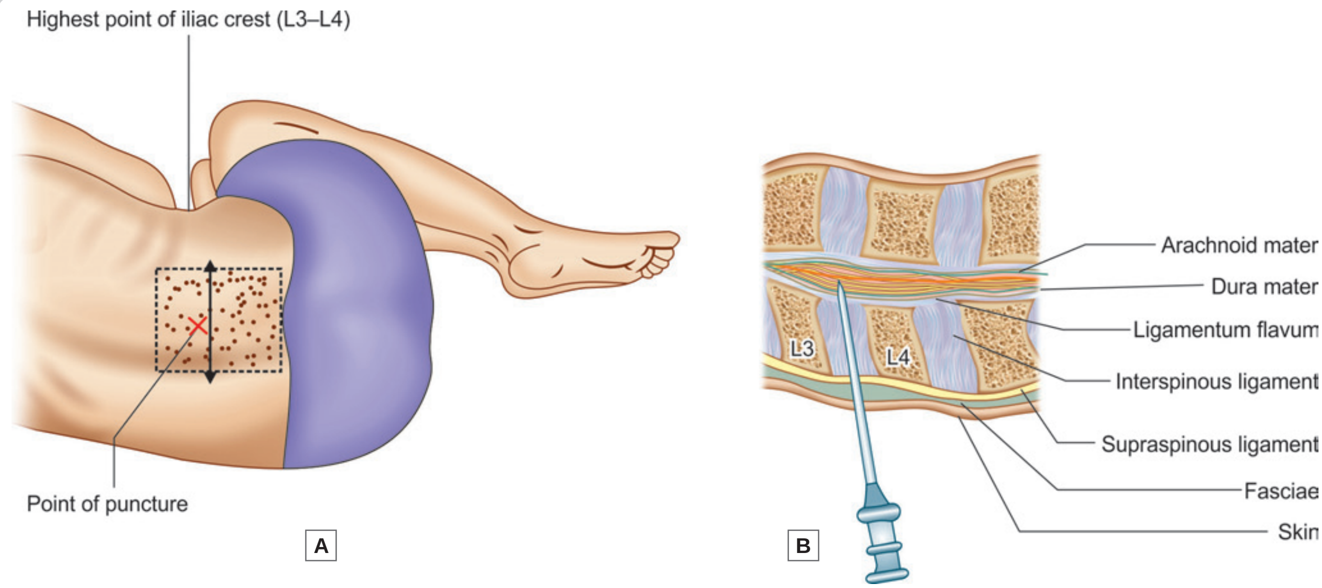


Figure 5.18: A. The site of lumbar puncture; **B.** Anatomical layers pierced to reach the subarachnoid space

Between the lower end of the spinal cord and the second sacral vertebral level the spinal subarachnoid space is quite wide and is called as ***lumbar cistern*** and contains the spinal nerve roots forming the cauda equina.

In this region, a needle can be introduced into the subarachnoid space without danger of injury to the spinal cord and CSF can be withdrawn for analysis. This procedure is called ***lumbar puncture*** (Figure 5.18).

Clinical Correlation

Lumbar puncture

Lumbar puncture is performed to obtain samples of cerebrospinal fluid for various diagnostic and therapeutic purposes. In this procedure, a needle is introduced into the subarachnoid space through the interval between the third and fourth lumbar vertebrae (Figure 5.18A).

With the patient lying on his or her side or in the upright sitting position, with the vertebral column well flexed, the space between adjoining laminae in the lumbar region is increased to a maximum. Taking full aseptic precautions, the lumbar puncture needle is inserted into the vertebral canal above or below the fourth lumbar spine. An imaginary line joining the highest points on the iliac crests passes over the fourth lumbar spine, this is taken as a landmark to insert the spinal needle.

Structures through which the needle passes during a lumbar puncture are (Figure 5.18B):

- Skin
- Superficial fascia
- Supraspinous ligament
- Interspinous ligament
- Ligamentum flavum
- Areolar tissue containing the internal vertebral venous plexus

Contd...

- Dura mater
- Arachnoid mater

Purpose of lumbar puncture

- The pressure of cerebrospinal fluid can be estimated roughly by counting the rate at which drops of cerebrospinal fluid flow out of the needle or more accurately, by connecting the needle to a manometer
- Samples of cerebrospinal fluid can be collected for examination. The important points to note about cerebrospinal fluid are its colour, its cellular content, and its chemical composition (specially the protein and sugar content)
- Lumbar puncture may be used for introducing air or radio-opaque dyes into the subarachnoid space for certain investigative procedures, e.g. Myelography. Drugs may also be injected for treatment
- Anesthetic drugs injected into the subarachnoid space act on the lower spinal nerve roots and render the lower part of the body insensitive to pain. This procedure, called **spinal anesthesia**, is frequently used for operations on the lower abdomen or on the lower extremities.

BLOOD SUPPLY OF SPINAL CORD

Arterial Supply

The arterial supply of the cord is derived from following arteries (Figure 5.19):

- Anterior spinal artery
- Two posterior spinal arteries
- The radicular arteries.

In addition to these channels, the pia mater covering the spinal cord has an arterial plexus (called the ***arterial vasocorona***), which also sends branches into the substance of the cord.

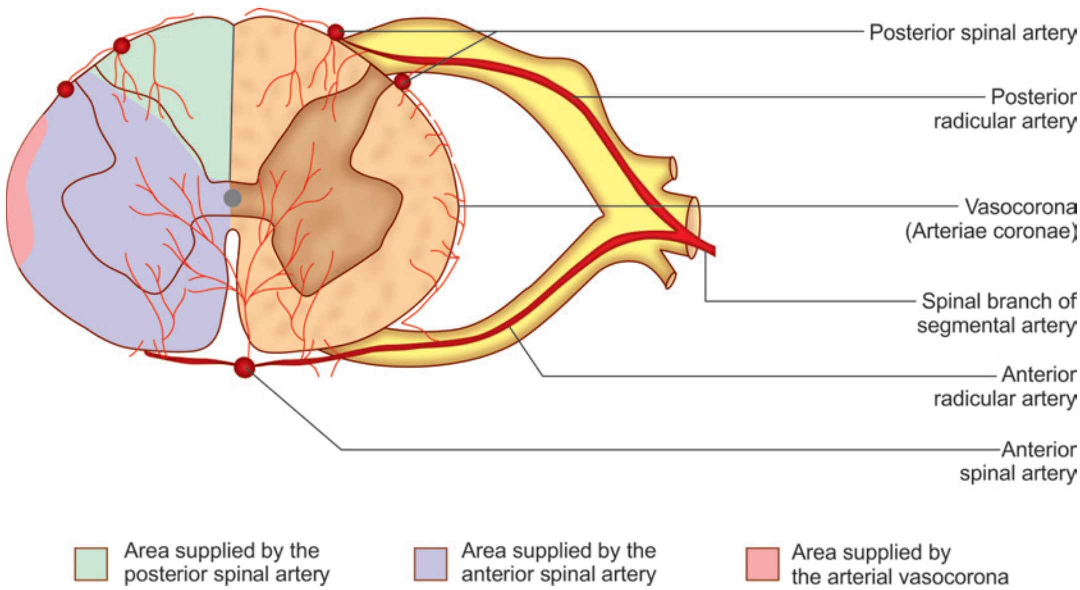


Figure 5.19: Intrinsic arterial supply of the spinal cord. In the left half of the figure the area showing green shading is supplied by the posterior spinal artery. The part showing pink shading is supplied by the arterial vasocorona, and the area with purple shading is supplied by the anterior spinal artery

Anterior Spinal Artery

The anterior spinal artery is formed in the posterior cranial fossa by the union of the right and left anterior spinal arteries (which are the branches of the fourth part of the vertebral artery). The anterior spinal artery descends through the foramen magnum and runs down in the anterior median fissure of the spinal cord.

Posterior Spinal Arteries

The right and left posterior spinal arteries are the branches of the fourth part of the vertebral arteries. Each posterior spinal artery descends through the foramen magnum as two branches, which pass one in front and the other behind the dorsal roots of the spinal nerves.

Radicular Arteries

The main source of blood to the spinal arteries is from the vertebral arteries (from which the anterior and posterior spinal arteries take origin). However, the blood from the vertebral arteries reaches only up to the cervical segments of the cord. Lower down, the spinal arteries receive blood through radicular arteries that reach the cord along the roots of spinal nerves. These radicular arteries arise from spinal branches of the vertebral, ascending cervical, deep cervical, intercostal, lumbar, and sacral arteries (Figure 5.20).

Arteria Radicularis Magna

Many of these radicular arteries are small and end by supplying the nerve roots. A few of them, which are larger, join the spinal arteries and contribute blood to them. One of the anterior radicular branches, usually from the right or left 11th intercostal artery is very large and is called the ***arteria radicularis magna*** **[*Artery of Adamkiewicz*]**. Its position is variable. This artery may be responsible for supplying blood to as much as the lower two-thirds of the spinal cord, especially the lumbar enlargement.

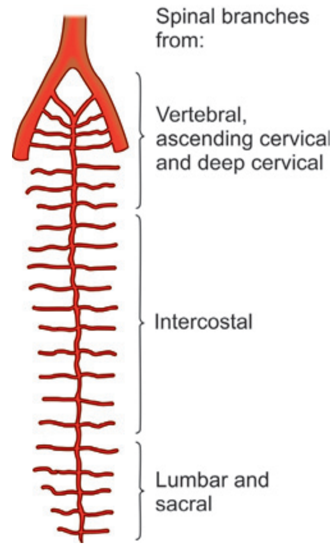


Figure 5.20: Radicular arteries that contribute blood to the spinal arteries

Intrinsic Blood Supply

The greater part of the cross-sectional area of the spinal cord, roughly the anterior two-thirds, is supplied by branches of the anterior spinal artery (Figure 5.18). These branches enter the anterior median fissure (or sulcus) and are, therefore, called ***sulcal branches.*** Alternate sulcal branches pass to

the right and left sides. They supply the anterior and lateral grey columns and the central grey matter. They also supply the anterior and lateral funiculi. The rest (posterior one-third) of the spinal cord is supplied by the posterior spinal arteries (Figure 5.18). As already mentioned, branches from the arteria vasocorona also supply the cord.

Clinical Correlation

Anterior spinal artery syndrome

Thrombosis in the anterior spinal artery produces a characteristic syndrome. The territory of supply includes the corticospinal tracts. This leads to an upper motor neuron paralysis below the level of lesion. The spinothalamic tracts are also involved. This leads to loss of sensations of pain and temperature below the level of lesion. Touch and conscious proprioceptive sensations are not affected as the posterior column tracts are not involved. The extent of damage varies depending on the efficiency of anastomoses in the region.

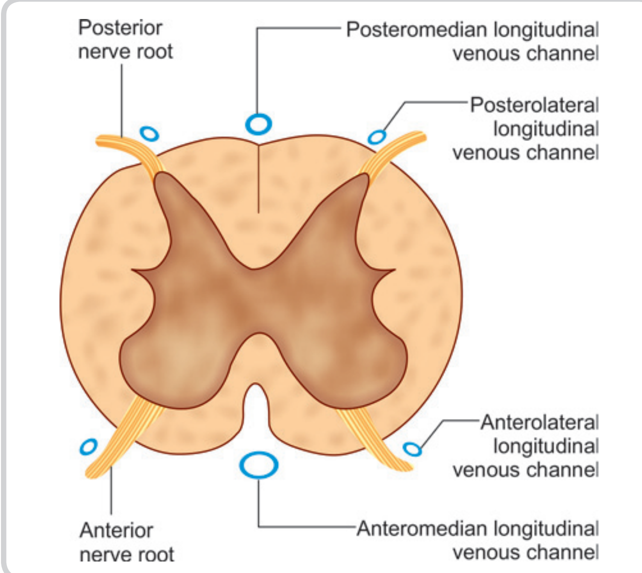


Figure 5.21: Venous drainage of the spinal cord

Venous Drainage

The veins draining the spinal cord are arranged in the form of six longitudinal channels (Figure 5.21). These are:

- ***Two median longitudinal channels***, one in the anterior median fissure called the anteromedian channel, and the other in the posteromedian sulcus called the posteromedian channel.
- ***The paired anterolateral channels***, one on either side, posterior to the anterior nerve roots.
- ***The paired posterolateral channels***, one on either side posterior to the posterior nerve roots.

These channels are interconnected by a plexus of veins that form a ***venous vasocorona***. The blood from these veins is drained into radicular veins that open into a venous plexus lying between the dura mater and the bony vertebral canal (***epidural*** or ***internal vertebral venous plexus***) and through it, into various segmental veins.

Multiple Choice Questions

1. At birth, the lower end of spinal cord lies at the level of which vertebra?
A. L1
B. L3
C. S2
D. S4

2. In adults, the length of the spinal cord in cms is
A. 25
B. 35
C. 45
D. 55

3. Inferior continuation of the pia mater of spinal cord is called as
A. Conus medullaris
B. Cauda equina
C. Filum terminale
D. Ganglion impar

4. Ligamentum denticulatum is an extension from the
A. Posterior longitudinal ligament
B. Pia mater
C. Ligamentum flavum
D. Dura mater

5. The surface landmark used for inserting the needle while doing lumbar puncture is
A. Highest point of iliac crest
B. Posterior superior iliac spine
C. Tubercle of iliac crest
D. Anterior superior iliac spine

6. Total number of spinal segments is
A. 30
B. 31
C. 32
D. 33

7. 9th thoracic spine corresponds to which spinal segment?
A. T9
B. T10
C. T11
D. T12

8. Cervical enlargement of the spinal cord extends between which of the following spinal segments?
A. C1 and C8
B. C1 and T2
C. C3 and C8
D. C3 and T2

Contd...

9. Spinal segments responsible for biceps tendon reflex are
A. C5, C6
B. C6, C7
C. C7, C8
D. C8, T1

10. Spinal segments responsible for plantar reflex are
A. L3. L4
B. L5, S1, S2
C. S2, S3, S4
D. S3, S4

11. Which artery gives rise to arteria radicularis magna (Artery of Adamkiewicz)?
A. Vertebral
B. 5th intercostal
C. 11th intercostal
D. 1st lumbar

12. Anterior spinal artery is a branch of which of the following arteries?
A. Internal carotid
B. Vertebral
C. Subclavian
D. Posterior inferior cerebellar

Answers

1. B **2.** C **3.** C **4.** B **5.** A **6.** B **7.** D **8.** D **9.** A **10.** B
11. C **12.** B

Chapter **6**

Spinal Cord – Internal Features

Specific Learning Objectives

At the end of learning, the student shall be able to:

- Describe the various nuclei in the anterior, posterior and lateral grey columns of the spinal cord
- Describe the various tracts in the anterior, lateral and posterior funiculi of the spinal cord
- Draw and label a transverse section of the spinal cord depicting important nuclear groups in the grey columns and important ascending and descending tracts in the white columns
- Explain the anatomical basis of clinical conditions affecting the grey and white matter of the spinal cord

INTRODUCTION

Internally, spinal cord shows grey matter surrounded by white matter. In transverse section the grey matter of the spinal cord forms an H-shaped or a butterfly shaped mass (Figure 6.1). In each half of the cord, the grey matter is divisible into a larger ventral mass, the ***anterior (or ventral) grey column***, and a narrow elongated ***posterior (or dorsal) grey column*** (Figure 6.2). In the thoracic and the sacral parts of the spinal cord, a small lateral projection of grey matter is seen between the ventral and dorsal grey columns. This is the ***lateral grey column***. The grey matter of the right and left halves of the spinal cord is connected across the midline by the ***grey commissure*** which is traversed by the ***central canal.*** The lower end of the central canal expands to form the ***terminal ventricle*** which lies in the conus medullaris. The cavity within the spinal cord continues for a short distance into the filum terminale. At the upper end, this central canal is continuous with the central canal of the medulla oblongata. The central canal is lined by ependyma and contains cerebrospinal fluid.

The white matter of the spinal cord is divided into right and left halves, in front by the ***anterior median fissure*** and behind by the ***posterior median septum***. In each half of the cord the white matter between the dorsal grey column and the posteromedian septum forms the ***posterior funiculus***

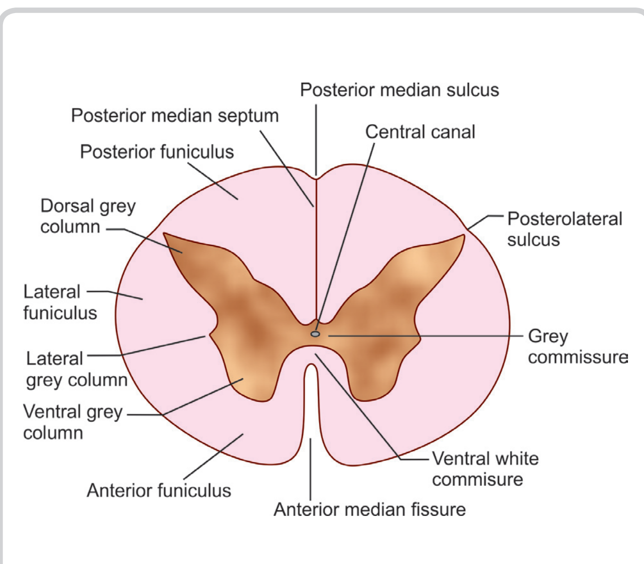


Figure 6.1: Transverse section through the spinal cord showing grey and white matter

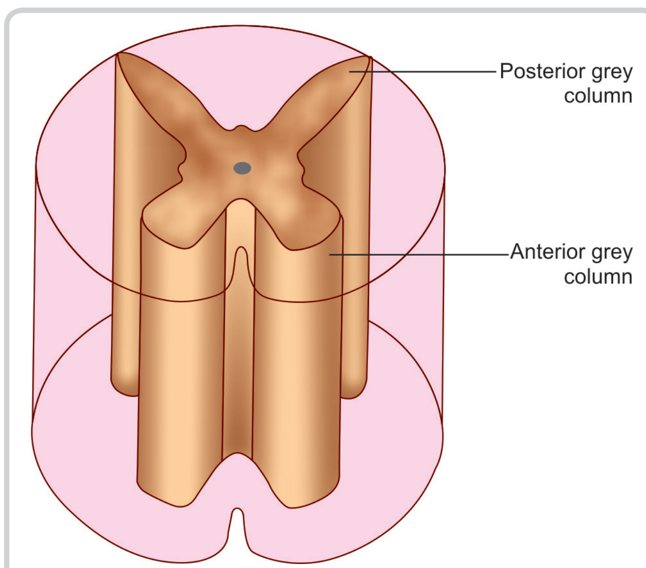


Figure 6.2: Three dimensional view of grey matter of a segment of the spinal cord, to explain the use of the term column for subdivisions of grey matter

(or posterior white column). The white matter between the anterior grey column and the anteromedian fissure forms the ***anterior funiculus*** (or anterior white column), while the white matter lateral to the anterior and posterior grey columns between the anterolateral sulcus and the posterolateral sulcus forms the ***lateral funiculus***. (The anterior and lateral funiculi are sometimes collectively referred to as the ***anterolateral funiculus***.) (Figure 6.1)

The white matter of the right and left halves of the spinal cord is continuous across the midline as the ***ventral white commissure*** which lies anterior to the ***grey commissure***. Some myelinated fibres running transversely in the grey commissure, posterior to the central canal are referred to as the ***dorsal white commissure***.

Variation in the Internal Structure of Spinal Cord at Different Levels

The relative amount of grey and white matter, and the shape and size of the grey columns, vary at different levels of the spinal cord (Figure 6.3). The amount of grey matter to be seen at a particular level can be correlated with the mass of tissue to be supplied. It is, therefore, greatest in the region of the cervical and lumbar enlargements which supply the limbs. The amount of white matter undergoes progressive increase from the lower part to the upper part of the spinal cord. This is a result of the fact that:

- Progressively more and more ascending fibres are added as the upper levels of the cord are reached.
- The number of descending fibres decreases as lower levels of the cord are reached as some of them terminate in each segment.

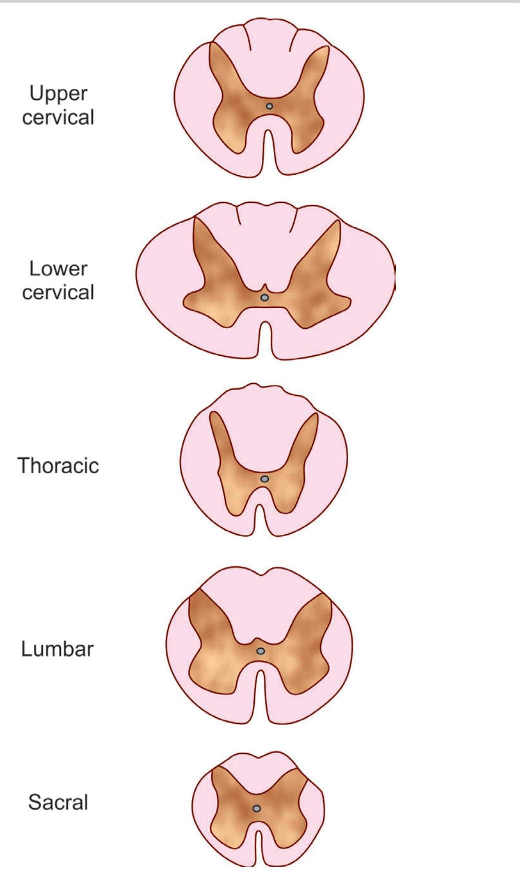


Figure 6.3: Diagrams to show differences in appearance of transverse sections through various levels of the spinal cord

NUCLEI IN GREY MATTER

Discrete collections of neurons (or nuclei) occur in various regions of the spinal grey matter. These are illustrated in Figure 6.4 and Table 6.1.

Nuclei in the Anterior Grey Column (Ventral horn)

The nerve cell groups in this column are motor nuclei. These are arranged in three groups—medial, lateral, and central (Figure 6.5).

- The ***medial group*** innervates the axial musculature of neck and trunk. It may be subdivided into ***dorsomedial*** and ***ventromedial*** parts.
- The ***lateral group*** is confined to cervical and lumbosacral enlargement and supplies the limb muscles. It consists of ***dorsolateral, ventrolateral,*** and ***retrodorsolateral*** parts.
- The ***central group*** is represented by the ***phrenic*** and ***accessory nuclei*** (in the cervical region) and by the ***lumbosacral nucleus*** (in the lumbosacral region).
    - ***Phrenic nucleus*** extends from C3 to C5 segments of the spinal cord and innervates the diaphragm.
    - ***Spinal nucleus of accessory (XI) nerve*** extends from C1 to C5 segments of the spinal cord and gives origin to spinal root of accessory nerve which supplies the trapezious and sternocleidomastoid muscles.
    - ***Lumbosacral nucleus*** extends from L2 to S3 segment; and supplies unknown muscles.

Nuclei in the Posterior Grey Column (Dorsal Horn)

This group consists of sensory nerve cells (Figure 6.6). From apex to base, they are as follows—marginal nucleus, substantia gelatinosa of Rolando, nucleus proprius, Clarke's column (nucleus dorsalis), and visceral afferent nucleus.

- ***Substantia gelatinosa*** situated at the apex is composed of cell body of sensory neurons and small-sized neurons and interneurons. It extends along the entire length of the spinal cord. Traced above, it is continuous with the nucleus of the spinal tract of trigeminal nerve. The substantia gelatinosa is traversed by the fibres of the dorsal nerve roots, which are the axons of neurons situated in the dorsal root ganglia and

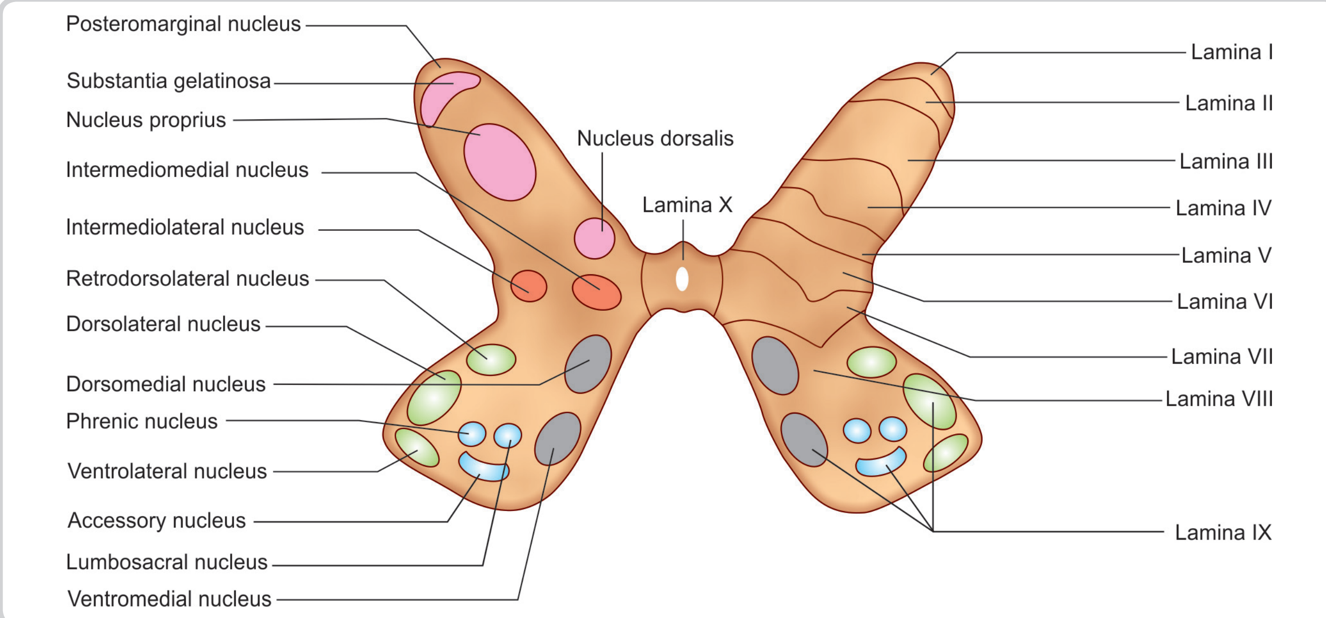


Figure 6.4: Subdivisions of the grey matter of the spinal cord – The left half of the figure shows the cell groups and the right half shows the laminae

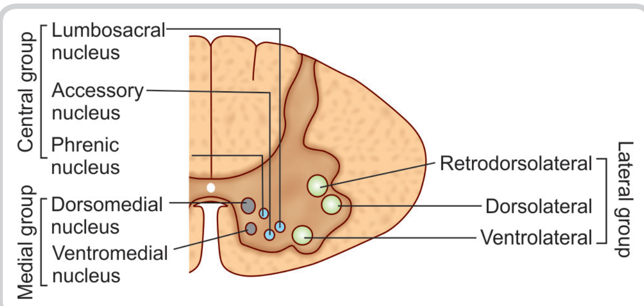


Figure 6.5: Nerve cell groups in the anterior and lateral grey column

carry the peripheral sensation of pain and temperature. Some of these fibres make synapses with the substantia gelatinosa cells, while others pass more deeply to the cells of nucleus proprius.

- A thin layer of cells lying superficially constitutes the ***posteromarginal nucleus***, also called the ***marginal zone***.
- ***Nucleus proprius*** lies deep to the substantia gelatinosa and constitutes the head and neck of the dorsal horn of grey matter. It extends along the entire length of the spinal cord. It consists of second-order sensory neurons, whose axons form the lateral spinothalamic tract.

Table 6.1 | Nerve Cell Groups in the Spinal Grey Columns

Nuclei in grey column	Extent in the spinal cord	Functions
Dorsal grey column		
Marginal nucleus	Entire cord	Relay station for pain and thermal stimuli Gives origin to fibres of spinothalamic tract of the opposite side
Substantia gelatinosa	Entire cord	Relay station for pain and thermal stimuli Modification of transmission of sensory input
Nucleus proprius	Entire cord	Gives origin to ventral spinothalamic tract
Nucleus dorsalis (Clarke's column)	C8 to L3	Gives origin to dorsal spinocerebellar tract
Lateral column		
Intermediolateral nucleus	T1 to L2	Gives origin to preganglionic sympathetic motor fibres
Intermediomedial nucleus	S2 to S4	Gives origin to preganglionic parasympathetic motor fibres
Ventral grey column		
Medial group of nuclei	Entire cord	Innervates muscles of the trunk
Phrenic nucleus	C3 to C5	Innervates the muscles of diaphragm
Spinal accessory nucleus	C1 to C5	Innervates trapezius and sternocleidomastoid muscles
Lumbosacral nucleus	L2 to S1 or S2	Innervates the unknown muscles
Lateral group of nuclei	C3 to T2 and L1 and S3	Innervates the muscles of girdles and limbs

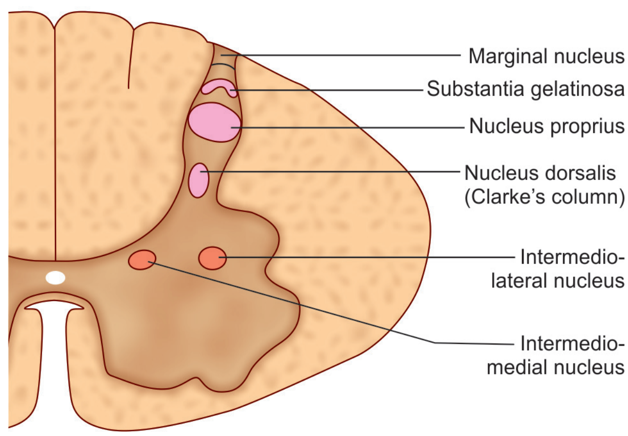


Figure 6.6: Nerve cell groups in the posterior grey column

- ***Nucleus dorsalis*** (Clarke's column) occupies the base of the dorsal horn and extends from C8 to L4 segments of the spinal cord. It consists of neurons, which receive proprioceptive impulses from neuromuscular spindles and tendon end organs. The axons (efferents) of this nucleus form the ipsilateral dorsal (posterior) spinocerebellar tract.

Nuclei in the Intermediate (Lateral) Grey Column

Between the ventral and dorsal grey columns, an ***intermediate zone*** contains the ***intermediolateral*** and ***intermediomedial*** nuclei (Figure 6.4).

- ***Intermediolateral nucleus*** extends from T1 to L2 segments of the cord and gives origin to preganglionic fibres of the sympathetic nervous system (*thoracolumbar outflow*) which leave the cord along with anterior nerve roots and reach the corresponding ganglia of sympathetic chain via the white rami communicantes.

  Note: T1 to L2 spinal nerves have white rami communicantes in addition to grey rami communicantes, which are present in all the spinal nerves, carrying the postganglionic sympathetic fibres, which arise from the sympathetic chain.

- ***Intermediate group of nucleus*** from S2 to S4 segments of the cord gives origin to preganglionic fibres of parasympathetic nervous system (***sacral outflow***), which also pass out through the ventral roots of the corresponding mixed spinal nerve and then, leave the spinal nerves to form the pelvic splanchnic nerves.

Division of Spinal Grey Matter into Laminae (Rexed Laminae)

From the point of view of neuronal connections, the grey matter of the spinal cord may be divided into 10 areas or laminae. These are illustrated in the right half of Figure 6.4 and Table 6.2.

Lamina I corresponds to the posteromarginal nucleus (lamina marginalis; fibres conveying pain and temperature relay here), ***lamina II*** to the substantia gelatinosa, and ***laminae III*** and ***IV*** to the nucleus proprius (laminae I to IV correspond to the head of the dorsal grey column; some workers include lamina III in the substantia gelatinosa). Afferent fibres carrying sensations from the skin end predominantly, in laminae I to IV. ***Lamina V*** corresponds to the neck of the dorsal grey column, and ***lamina VI*** to the base. The lateral part of lamina V corresponds to the formatio reticularis. Proprioceptive impulses reach laminae V and VI. These laminae also receive numerous fibres from the cerebral cortex. ***Lamina VII*** corresponds to the intermediate grey matter and includes the intermediomedial, intermediolateral, and dorsal nuclei. Lamina VII gives off fibres that reach the midbrain and cerebellum (through spinocerebellar, spinotectal, and spinoreticular tracts). It receives fibres from these regions through tectospinal, reticulospinal, and rubrospinal tracts. At the level of the cervical and lumbar enlargements, this lamina extends into the lateral part of the ventral horn. Renshaw cells are located in a forward extension of lamina VII (into the interval between laminae VIII and IX). ***Lamina VIII*** occupies most of the ventral horn in the thoracic segments, but at the level of the limb enlargements, it is confined to the medial part of the ventral horn. Lamina VIII is made up mainly of interneurons that receive fibres

Table 6.2 | Rexed Laminae and Nuclear Groups

Laminae	Corresponding grey column nuclei
I	Posteromarginal nucleus (lamina marginalis)
II	Substantia gelatinosa of Rolando
III and IV	Nucleus propius
V and VI	Neck and base of dorsal grey column, Clarke's column
VII	Intermediate region of grey matter including Nucleus dorsalis (Clarke's column), interomediomedial, and interomediolateral nuclei of lateral horn
VIII and IX	Medial and lateral groups of ventral horn nuclei
X	Grey matter around the central canal consisting mainly of neuroglial cells (substantia gelatinosa centralis)

from various sources. They send their efferents to γ-motor neurons and, thus, influence muscle spindles.

Lamina IX is made up of the various discrete groups of ventral horn cells. Lamina IX contains the α- and γ-motor neurons that give off efferent fibres to skeletal muscle. Motor neurons in different parts of the ventral grey column show remarkable differences in the orientation and extent of their dendritic fields. Many of the dendrites of neurons in the ventromedial, central, and ventrolateral columns run longitudinally in the form of bundles. These neurons, therefore, come into intimate contact with each other. This arrangement is seen in relation to neurons that supply postural muscles. In contrast, the dendrites of neurons in the dorsolateral column have very little contact with those of neighboring neurons. This column supplies muscles in distal parts of the limbs and the discrete nature of the neurons may be associated with fine control necessary for movements produced by these muscles. ***Lamina X*** forms the grey matter around the central canal.

From the point of view of function and of neuronal organization, it has been proposed that (instead of division into ventral and dorsal grey columns) the spinal grey matter should be divided into a ***central core*** where the organization of neurons is diffuse and non-discriminative and into ***dorsal and ventral appendages***. Laminae VII and VIII have been (tentatively) assigned to the central core, laminae I to VI to the dorsal appendage, and lamina IX to the ventral appendage.

Types of Neurons in the Spinal Grey Column

Anterior Grey Column

The ***ventral horn cells*** of the spinal cord may be functionally divided as follows:

- ***Alpha (α) motor neurons:*** The most prominent neurons with large cell bodies and prominent Nissl substance are designated as ***α-motor neurons***. These are somatic efferent neurons. Their axons (***α-efferents)*** leave the spinal cord through the ventral nerve roots of the spinal nerves and innervate skeletal muscle. They occupy lamina IX of the ventral grey column.
- ***Gamma (γ) motor neurons:*** Some smaller neurons designated as ***γ-motor neurons*** are also located in lamina IX. They supply intrafusal fibres of muscle spindles. Sensory impulses arising in the spindle travel to the spinal cord and reach the α-motor neurons. The γ-motor neurons, thus, influence the activity of α-motor neurons indirectly through muscle spindles.
- ***Interneurons:*** A considerable number of smaller neurons in the ventral grey column are internuncial neurons. They are most abundant in lamina VIII. Some ramifications of the central processes of cells in the dorsal nerve root ganglia (bringing afferent impulses from the periphery) and axons descending from higher centres terminate in relation to these internuncial neurons. The axons of internuncial neurons convey these impulses to α- and γ-motor neurons.
- ***Renshaw cell:*** Another variety of neuron that is believed (on physiological grounds) to exist in the ventral grey column is the so called ***Renshaw cell***. These cells receive the terminations of collaterals arising from the axons of α-motor neurons. The axons of Renshaw cells carry the impulses back to the cell bodies of the same α-motor neurons, and, thus, help regulate their activity.

Posterior Grey Column

The ***neurons of the dorsal grey column*** may be subdivided as follows:

- Some of these are internuncial neurons similar to those in the ventral grey column.
- Many dorsal column neurons receive afferent impulses through the central processes of neurons in dorsal nerve root ganglia. These dorsal column neurons give off axons that enter the white matter of the spinal cord, either on the same or opposite sides. These axons may behave in one of the following ways:
  - They may ascend or descend for some segments before terminating in relation to neurons at other levels of the spinal cord. Such axons constitute ***intersegmental tracts***.
  - A considerable number of axons arising from dorsal column neurons run upwards in the spinal cord and constitute ***ascending tracts,*** which terminate in various masses of grey matter in the brain. These tracts form a considerable part of the white matter of the spinal cord.

Lateral Grey Column

The ***neurons of the intermediolateral group*** (lateral grey column) are visceral efferent neurons. They are present at two levels of the spinal cord:

- One group is present in the thoracic and upper two or three lumbar segments. These are preganglionic neurons of the sympathetic nervous system. Their axons terminate in the neurons in sympathetic ganglia. Axons of these postganglionic neurons are distributed to various organs and to blood vessels.
- The second group of visceral efferent neurons is found in the second to fourth sacral segments of the spinal cord. These are preganglionic neurons of the parasympathetic nervous system. Their axons leave the spinal cord through the ventral nerve roots to reach spinal nerves. They leave the spinal nerves as the ***pelvic splanchnic nerves,*** which are distributed to

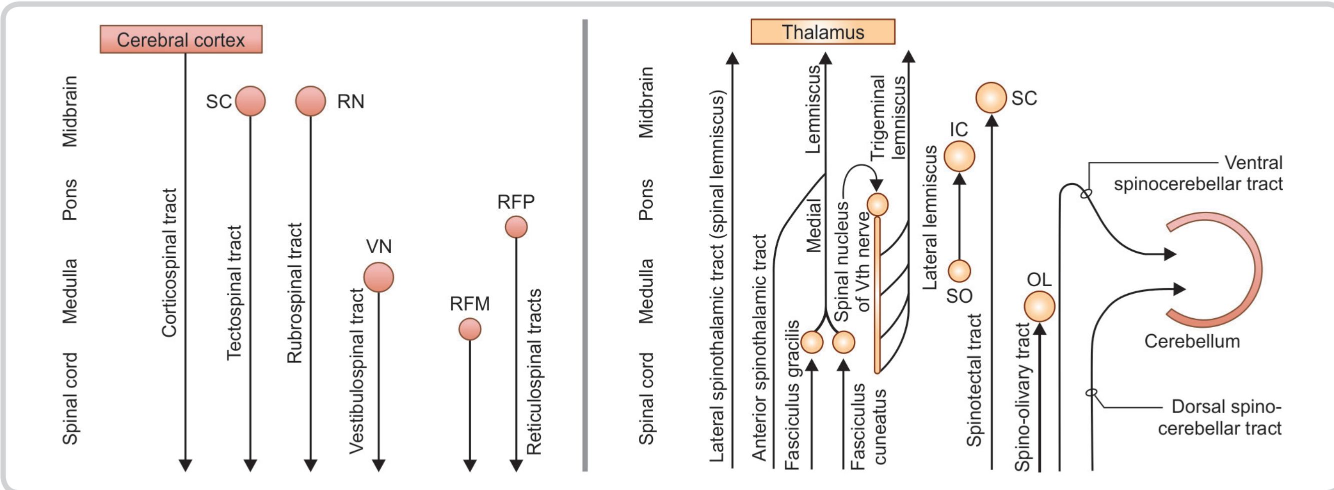


Figure 6.7: Scheme to show the major tracts passing through the brainstem
(SC = Superior colliculus. RN = Red nucleus. VN = Vestibular nuclei. RFP = Reticular formation of pons. RFM = Reticular formation of medulla IC = Inferior colliculus. SO = Superior olivary nucleus. OL = Inferior olivary nucleus)

some viscera in the pelvis and abdomen. They end by synapsing with ganglion cells located in the wall of the viscera concerned. The postganglionic fibres arising in these ganglia are short and supply smooth muscles and glands within these viscera.

TRACTS IN WHITE MATTER

A collection of nerve fibres within the central nervous system, that connects two masses of grey matter, is called a ***tract*** and this collection of nerve fibres have the same origin, course, and termination. Tracts may be ascending or descending. They are usually named after the masses of grey matter connected by them. Thus, a tract beginning in the cerebral cortex and descending to the spinal cord is called the ***corticospinal tract***, while a tract ascending from the spinal cord to the thalamus is called the ***spinothalamic tract***. Tracts are sometimes referred to as ***fasciculi*** (bundles) or ***lemnisci*** (ribbons). The major tracts passing through the spinal cord are shown schematically in Figure 6.7 and in Table 6.3. The position of the tracts in a transverse section of the spinal cord is shown in Figure 6.8.

Descending Tracts

Lateral and Anterior Corticospinal Tracts

These tracts are made up, predominantly, of axons of neurons lying in the motor area of the cerebral cortex (area 4). Some fibres also arise from the premotor area (area 6) and some from the somatosensory area (areas 3, 1, 2). After passing through the internal capsule, the fibres enter the crus cerebri (of the midbrain) and then descend through the ventral part of the pons to enter the pyramids in the upper part of the medulla. Near the lower end of the medulla about 80 percent of the fibres cross to the opposite side and enter the lateral funiculus of the spinal cord and descend as the ***lateral corticospinal tract*** (Figure 6.8).

Table 6.3 | Important ascending and descending tracts in various funiculi

Funiculus	Ascending tracts	Descending tracts
Posterior	• Fasciculus gracilis • Fasciculus cuneatus	• Fasciculus interfascicularis (Semilunar tract/ Comma tract of Schultze) • Septomarginal tract
Lateral	• Posterior spinocerebellar • Anterior spinocerebellar • Lateral spinothalamic • Spinotectal • Spinoreticular • Dorsolateral (Lissauer's tract)	• Lateral corticospinal • Rubrospinal • Lateral reticulospinal • Olivospinal • Descending autonomic fibres
Anterior	• Anterior spinothalamic • Spino-olivary • Spinotectal • Spinoreticular	• Anterior corticospinal • Lateral vestibulospinal • Medial vestibulospinal • Tectospinal • Medial reticulospinal

TRANSVERSE SECTION OF SPINAL CORD

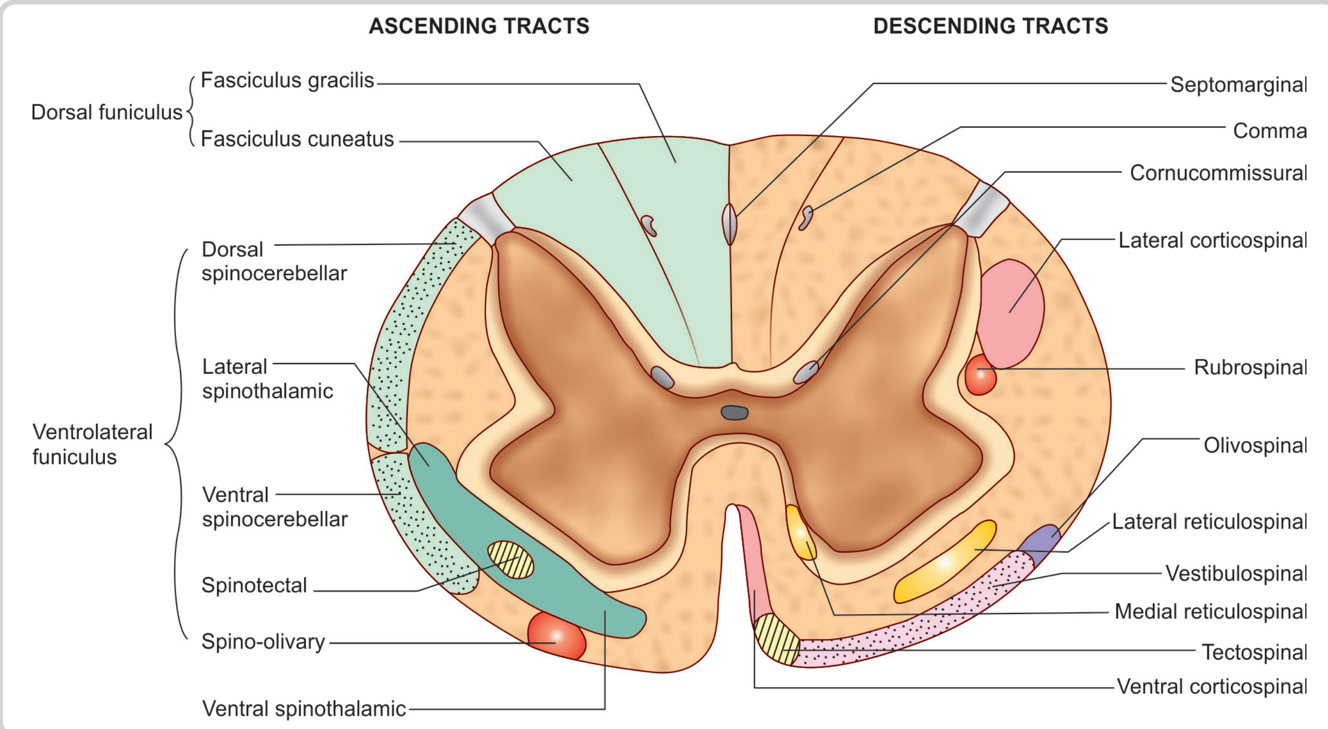


Figure 6.8: Simplified scheme to show the positions of the main ascending and descending tracts present in a transverse section of the spinal cord Note that the positions of the tracts vary at different levels of the cord and that the areas occupied by the fibres of different tracts overlap considerably.

The fibres of this tract terminate in grey matter at various levels of the spinal cord (Figure 18.9).

Fibres of the corticospinal tracts are arranged somatotopically. The corticospinal fibres that do not cross in the pyramidal decussation enter the anterior funiculus of the spinal cord to form the ***anterior corticospinal tract.*** On reaching the appropriate level of the spinal cord the fibres of this tract cross the midline (through the anterior white commissure) to reach grey matter on the opposite side of the cord (Figure 18.9).

The cerebral cortex controls voluntary movement through the corticospinal tract. Interruption of the tract anywhere in its course leads to paralysis of the muscles concerned. Fibres of the corticospinal tracts are often referred to as ***upper motor neurons*** in distinction to the ventral horn cells and their processes which constitute the ***lower motor neurons*** (Figure 6.9).

Rubrospinal Tract

This tract is made up of axons of neurons lying in the red nucleus (which lies in the upper part of the midbrain). The fibres of the tract cross to the opposite side in the lower part of the tegmentum of the midbrain. and pass through the pons and medulla to enter the lateral funiculus of the spinal cord (Figure 6.10). Here the tract lies just in front of the lateral corticospinal tract.

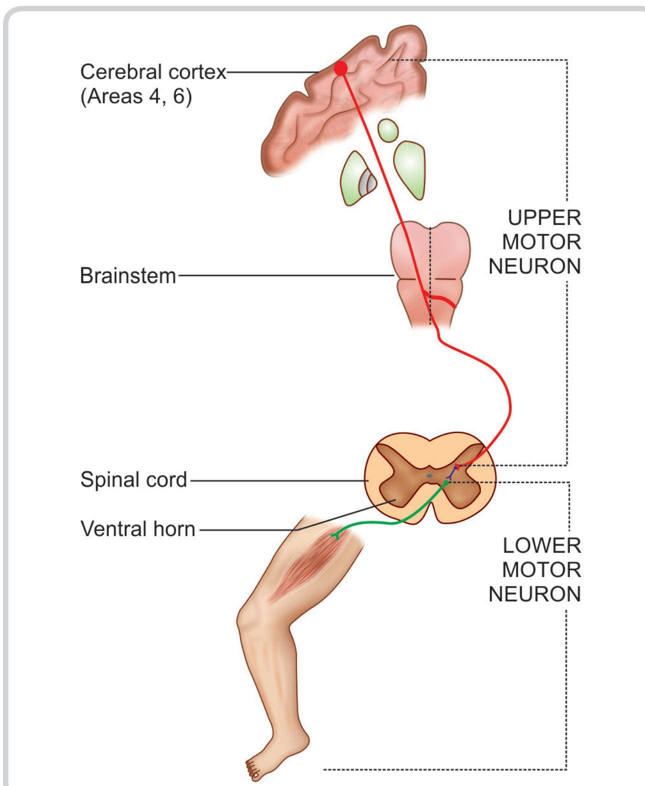


Fig. 6.9: Position of upper motor neuron and lower motor neuron in brain and spinal cord

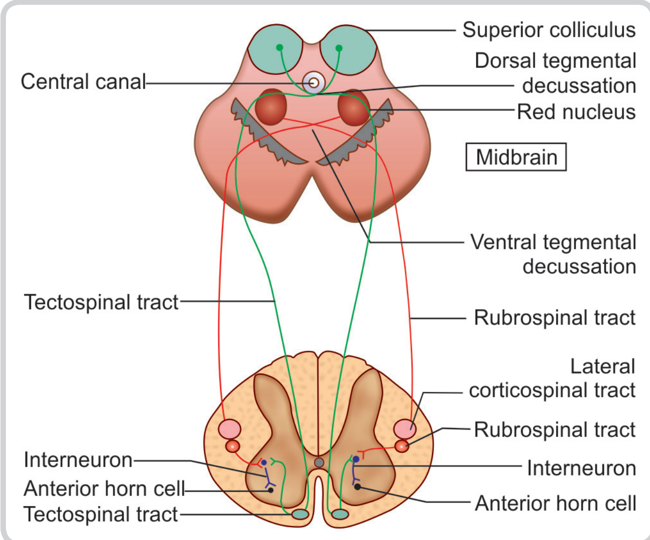


Fig. 6.10: Scheme to show the main features of tectospinal and rubrospinal tracts. Note that the fibres of both the tracts cross to the opposite side in midbrain (in dorsal and ventral tegmental decussation)

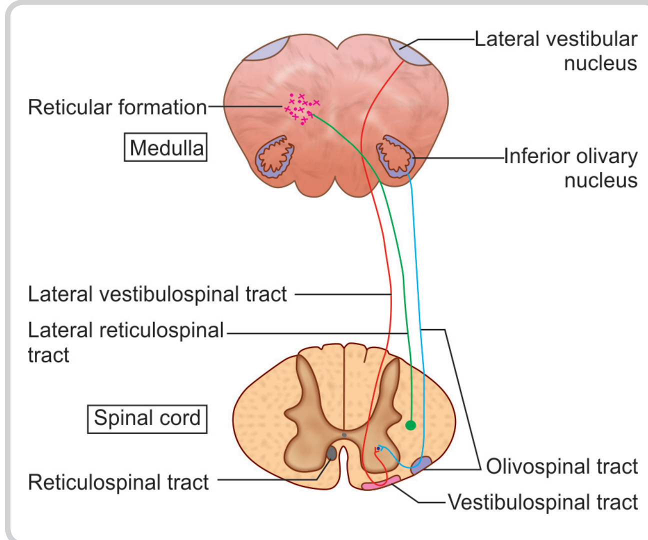


Fig. 6.11: Scheme to show the main features of vestibulospinal, olivospinal, and reticulospinal tracts

The tract is facilitatory to flexors and inhibitory to extensors.

Tectospinal Tract

The fibres of this tract arise from neurons in the superior colliculus (midbrain). The fibres cross to the opposite side in the upper part of the tegmentum of the midbrain and descend through the pons and medulla into the anterior funiculus of the spinal cord (Figure 6.10).

Medial and Lateral Vestibulospinal Tracts

Medial Vestibulospinal Tract

The medial vestibulospinal tract arises mainly from the medial vestibular nucleus located in the medulla oblongata (with some fibres from the inferior and superior nuclei). The tract descends through the anterior funiculus.

Lateral Vestibulospinal Tract

The neurons of origin of the lateral vestibulospinal tract lie in the lateral vestibular nucleus (medulla). This tract is uncrossed and lies in the anterior funiculus of the spinal cord (Figure 6.11) This tract is an important efferent path for equilibrium.

The lateral vestibulospinal tract is facilitatory to motor neurons supplying extensor muscles (of the neck, back and limbs); and is inhibitory to flexor muscles. The medial vestibulospinal tract is inhibitory to muscles of the neck and back.

Olivospinal Tract

This tract is generally described as arising from the inferior olivary nucleus (medulla) and terminating in relation to ventral horn cells of the cervical spinal cord (Figure 6.11).

Medial and Lateral Reticulospinal Tracts

Medial Reticulospinal Tract

Fibres arise from the medial part of the reticular formation of mainly pons (the oral and caudal reticular nuclei of the pons). The fibres which are crossed and uncrossed descend in the anterior funiculus (near the anterior median fissure). The tract is facilitatory to the extensor muscles of the trunk and limbs, but some fibres are inhibitory to neck muscles. The tract is concerned with postural adjustments of the head, trunk and limbs (Figure 6.11).

Lateral Reticulospinal Tract

This tract is constituted by fibres arising in the ventrolateral part of the reticular formation of the medulla (mainly from the nucleus gigantocellularis reticularis). The fibres cross to the opposite side in the medulla and run down in the lateral funiculus (Figure 6.11). The tract is facilitatory to the flexor muscles of the trunk and limbs. Automatic breathing is also controlled by lateral reticulospinal tract.

Apart from control of motor function, the reticulospinal tracts may influence transmission of pain through the ascending tracts.

Descending Autonomic Fibres

Hypothalamospinal fibres begin (mainly) in the paraventricular nucleus of the hypothalamus, and descend uncrossed in the dorsolateral funiculus.

Some fibres (noradrenergic) descend into the cord from the locus coeruleus. Some adrenergic fibres also descend from the medulla to the intermediolateral grey column.

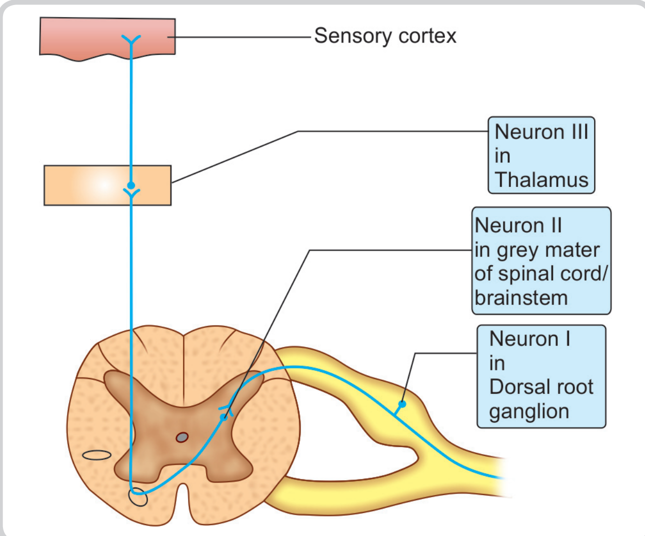


Fig. 6.12: Scheme to show the levels of neurons in ascending tract

Ascending tracts

The ascending tracts of the spinal cord and brainstem represent one stage of multineuron pathways by which afferent impulses arising in various parts of the body are conveyed to different parts of the brain. The ***first order neurons*** of these pathways are usually located in spinal (dorsal nerve root) ganglia (Figure 6.12 and Table 6.4). The neurons in these ganglia are pseudounipolar. Each neuron gives off a peripheral process and a central process. The peripheral processes of the neurons form the afferent fibres of peripheral nerves. They end in relation to sensory end organs (receptors) situated in various tissues. The central processes of these neurons enter the spinal cord through the dorsal nerve roots. Having entered the cord, the central processes, as a rule, terminate by synapsing with cells in spinal grey matter. Some of them may run upwards in the white matter of the cord to form ascending tracts (Figure 6.8). The majority of ascending tracts are, however, formed by axons of cells in spinal grey matter. These are ***second order*** sensory neurons. Second order neurons cross the midline. In the case of pathways that convey sensory information to the cerebral cortex the second order neurons end by synapsing with neurons in the thalamus. ***Third order*** sensory neurons located in the thalamus carry the sensations to the cerebral cortex Table 6.4.

Fasciculus Gracilis and Fasciculus Cuneatus (Posterior Column)

These tracts occupy the posterior funiculus of the spinal cord and are, therefore, often referred to as the ***posterior column tracts*** (Figure 6.8). They are unique in that they are formed predominantly by central processes of neurons located in dorsal root ganglia i.e., by first order sensory neurons. The fibres derived from the lowest ganglia are situated most medially; while those from the highest ganglia are most lateral. The fasciculus gracilis (Tract of Goll) which lies medially is therefore composed of fibres from the coccygeal, sacral, lumbar and lower thoracic dorsal root ganglia while the fasciculus cuneatus (Tract of Burdach) which lies laterally consists of fibres from upper thoracic and cervical dorsal root ganglia. The fibres of these fasciculi extend upwards as far as the lower part of the medulla. Here the fibres of the gracile and cuneate fasciculi terminate by synapsing with neurons in the nucleus gracilis and nucleus cuneatus respectively (Figure 18.2).

Anterior and Lateral Spinothalamic Tracts

- The first order neurons of this pathway are located in spinal ganglia. The central processes of these neurons enter the spinal cord and terminate in relation to spinal

Table 6.4 | Orders of Neurons in Some Important Ascending Tracts

Name of the tract	First order neuron	Second order neuron and site of crossing	Third order neuron	Functions of the tract
Fasciculus gracilis	Dorsal root ganglion	Nucleus gracilis—crossing in sensory decussation of medulla oblongata	Ventral posterolateral nucleus of thalamus	Discriminative touch, joint position, vibration sense
Fasciculus cuneatus	Dorsal root ganglion	Nucleus gracilis—crossing in sensory decussation of medulla oblongata	Ventral posterolateral nucleus of thalamus	Discriminative touch, joint position, vibration sense
Lateral spinothalamic tract	Dorsal root ganglion	Substantia gelatinosa, neurons in spinal laminae II, III, IV, V—crossing in ventral white commissure of spinal cord	Ventral posterolateral nucleus of thalamus	Pain, temperature
Anterior spinothalamic tract	Dorsal root ganglion	Substantia gelatinosa, neurons in spinal laminae IV, V—crossing in ventral white commissure of spinal cord	Ventral posterolateral nucleus of thalamus	Crude touch, pressure
Anterior spino-cerebellar tract	Dorsal root ganglion	Nucleus thoracicus of spinal cord	Nil	Unconscious proprioception
Posterior spino-cerebellar tract	Dorsal root ganglion	Nucleus thoracicus of spinal cord	Nil	Unconscious proprioception

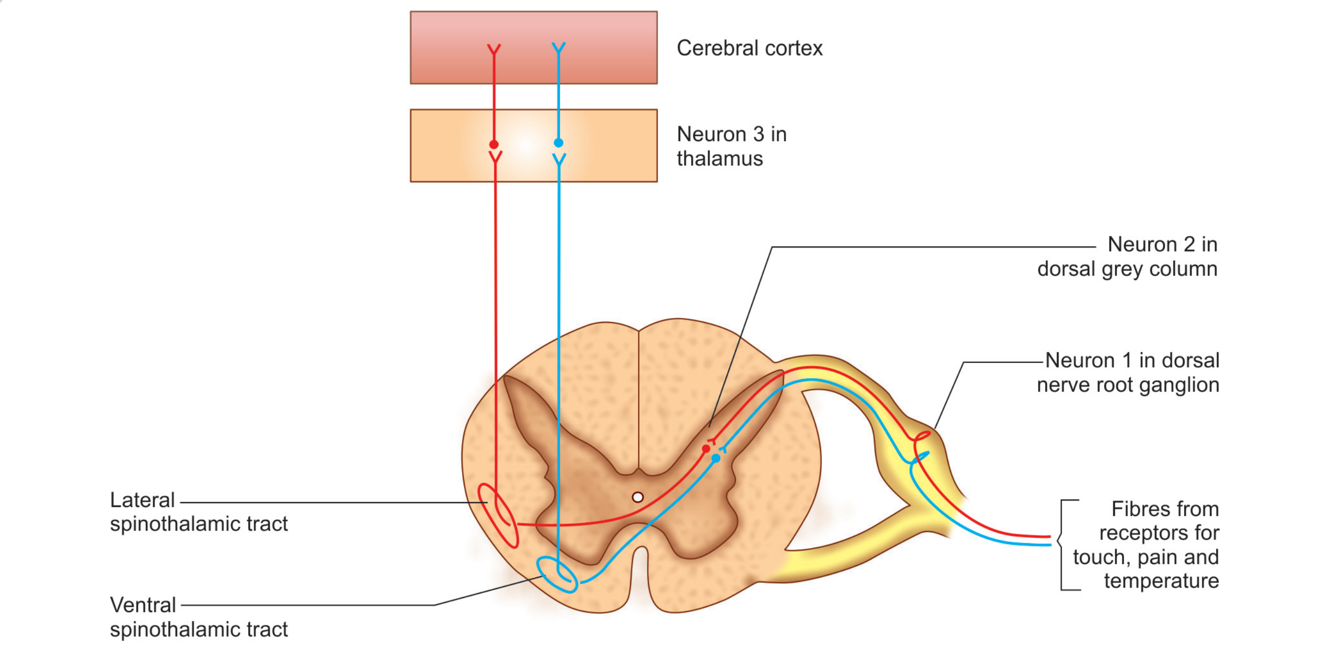


Figure 6.13: Scheme to illustrate the main features of the spinothalamic pathways

grey matter. They may ascend in the dorsolateral tract (situated near the tip of the dorsal grey column, Figure 6.8) for one or more segments before ending in grey matter

- The second order neurons of this pathway are located mainly in laminae II to V in substantia gelatinosa of Rolando and nucleus proprius. The axons of these neurons constitute the anterior and lateral spinothalamic tracts. They cross to the opposite side of the spinal cord in the white commissure. The crossing of the fibres is oblique (Figure 6.13). The fibres for the lateral spinothalamic tract cross within the same segment of the cord, while those of the anterior spinothalamic tract may ascend for one or more segments before they cross to the opposite side. The tracts also carry some uncrossed fibres (about 10 per cent).

  The fibres for the anterior spinothalamic tract enter the anterior funiculus (Figures 6.8 and 6.13) where they lie medial to emerging fibres of ventral nerve roots. The fibres for the lateral spinothalamic tract enter the lateral funiculus. The two tracts form one continuous band that runs up the spinal cord.

The anterior spinothalamic tract carries sensations of crude touch and pressure, while the lateral spinothalamic tract carries sensations of pain and temperature. It is now realised that although different fibres within the spinothalamic tracts carry different types of sensations, the anterior and lateral spinothalamic tracts constitute a single functional unit.

Anterior and Posterior Spinocerebellar Tracts

These pathways carry proprioceptive impulses arising in muscle spindles, Golgi tendon organs, and other receptors to the cerebellum (Figure 6.14). They constitute the afferent component of reflex arcs involving the cerebellum, for control of posture.

- The first order neurons of these pathways are located in dorsal root ganglia. Their peripheral processes end in relation to muscle spindles, Golgi tendon organs and other proprioceptive receptors. Some fibres are related to end organs concerned with exteroceptive sensations (touch, pressure). The central processes of the neurons concerned, ascend in the posterior funiculi for varying distances before ending in spinal grey matter. Some of them ascend all the way to the medulla and end in the accessory cuneate nucleus.
- The second order neurons of the pathway are arranged in a number of groups:
  - Neurons located in the dorsal nucleus (situated on the medial side of the base of the dorsal grey column in segments C8 to L3 of the spinal cord (Figure 6.8) give origin to fibres of the ***dorsal* (*posterior*) *spinocerebellar tract.*** This is an uncrossed tract lying in the lateral funiculus (Figure 6.8). It begins in the lumbar segments of the spinal cord and ascends to the medulla where its fibres become incorporated in the inferior cerebellar peduncle and pass through it to reach the vermis and paravermal region of the cerebellum on the same side (Figure 6.14).

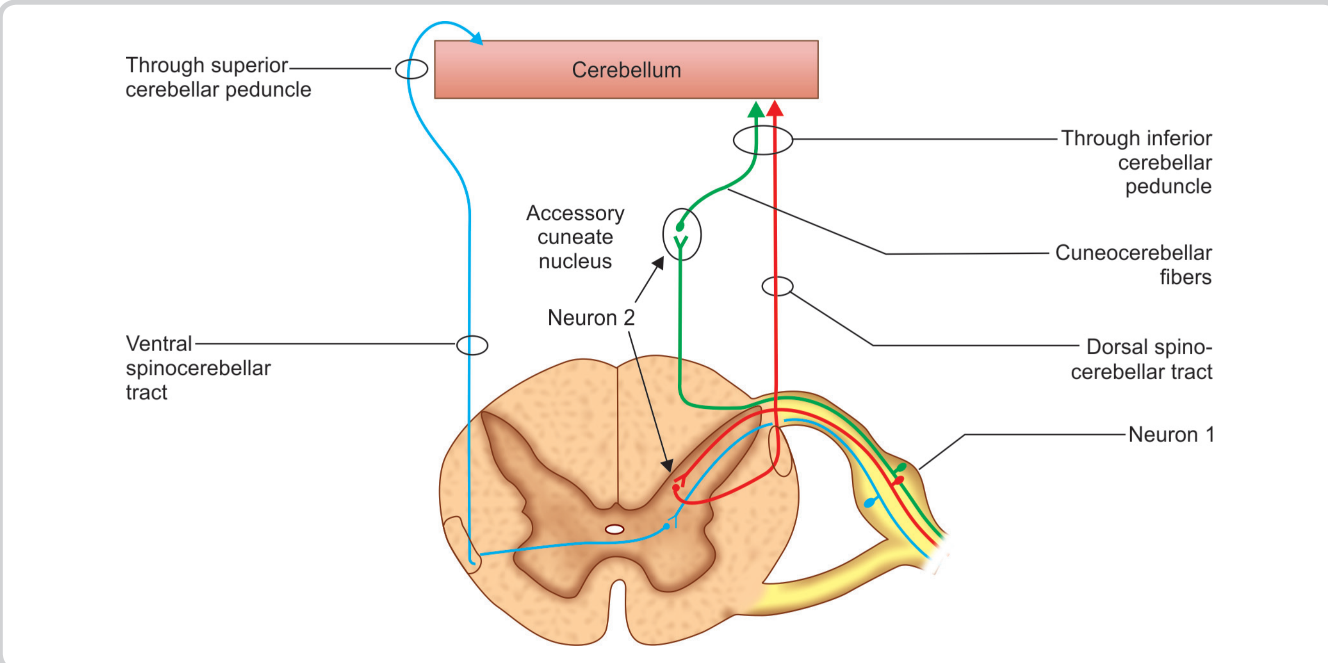


Figure 6.14: Scheme to show the main features of the spinocerebellar pathways

- The neurons giving origin to the ***ventral (anterior) spinocerebellar tract*** are located in the junctional area between the ventral and dorsal grey columns (laminae V, VI, VII) in the lumbar and sacral segments of the cord. Some of the neurons concerned lie in the ventral grey column (spinal border cells). The fibres of this tract are predominantly crossed. They ascend in the lateral funiculus, anterior to the fibres of the dorsal spinocerebellar tract (Figure 6.8), and pass through the medulla, pons and midbrain. At the lower part of midbrain the fibres turn downwards to enter the superior cerebellar peduncle through which they reach the vermis and paravermal region of the cerebellum bilaterally (Figure 6.14).

  From a functional point of view both the ventral and dorsal spinocerebellar tracts are concerned mainly with the lower limbs and trunk. The dorsal tract is believed to carry impulses concerned with fine co-ordination of muscles controlling posture, and with movements of individual muscles. On the other hand the ventral tract is concerned with movements of the limb as a whole.
- ***Rostral spinocerebellar pathway:*** This tract is believed to arise from spinal grey matter in cervical regions of the spinal cord. The neurons of origin lie in the lower four cervical segments (lamina VII). These neurons constitute the ***nucleus centrobasalis***.

  Most fibres of the pathway are uncrossed. They reach the cerebellum through the inferior and superior cerebellar peduncles. This pathway is regarded, functionally, as the forelimb equivalent of the ventral spinocerebellar tract.

Spinoreticular Tracts

Spinoreticular fibres begin from spinal neurons mainly in lamina VII (also V and VIII). The fibres are partly crossed and partly uncrossed. The fibres ascend in the ventrolateral part of the spinal cord, intermingling with spinothalamic tracts. They end in the reticular formation of the medulla and pons. The tract probably carries pain.

Spino-olivary Tract

The spino-olivary tract is also a crossed tract. It lies at the junction of the anterior and lateral funiculi of the spinal cord. The fibres of the tract end in accessory olivary nuclei.

Spinomesencephalic Tracts

A number of tracts travel from spinal cord to different areas in the midbrain. They are collectively referred to as spinomesencephalic tracts.

The ***spinotectal tract*** connects the spinal grey matter to the superior colliculus. It is a crossed tract. It carries impulses that regulate reflex movements of the head and eyes in response to stimulation of some parts of the body.

Clinical Correlation

Disorders of Motor Function

Inability to move a part of the body is referred to as ***paralysis.*** This can be produced by interruption of motor pathways anywhere between the motor area of the cerebral cortex and the muscles themselves. The first of these is located in the cerebral cortex. Its axons terminate in the spinal cord or in motor cranial nerve nuclei in the brainstem. From a physiological and clinical point of view, these neurons are referred to as the ***upper motor neurons (UMN)***. The second type of neurons is located in the anterior grey column of the spinal cord (or in motor nuclei of the brainstem) and they send out axons that travel through a peripheral nerve to innervate muscle. These neurons are referred to as the ***lower motor neurons (LMN).***

Destruction or interruption of the upper motor neuron is accompanied by an increase in muscle tone and exaggeration of tendon reflexes. It is, therefore, possible to distinguish between an upper motor neuron paralysis (often called ***spastic paralysis***) and a lower motor neuron (or ***flaccid***) paralysis. Paralysis may be confined to one limb (***monoplegia***) or to both limbs on one side of the body (***hemiplegia***). Paralysis of both lower limbs is called ***paraplegia,*** and that of all four limbs is called ***quadriplegia.*** When lower motor neurons are destroyed, or their continuity interrupted, the muscles supplied by them lose their tone (i.e. they become flaccid) and in course of time the muscles undergo atrophy. In addition, because of interruption of the efferent part of reflex pathways, tendon reflexes are abolished (Table 6.5).

Table 6.5 | Differences between Upper Motor Neuron (UMN) Lesion and Lower Motor Neuron (LMN) Lesion

Feature	Upper motor neuron lesion	Lower motor neuron lesion
Paralysis	Groups of muscles of one or more limbs paralysed	Individual muscles paralysed
Muscle tone	Spasticity/rigidity (spastic paralysis)	Flaccid (flaccid paralysis)
Deep tendon reflexes	Exaggerated	Absent
Superficial reflexes like abdominal and cremasteric reflexes	Absent	Absent
Plantar response	Extensor (Babinski sign positive)	No response
Muscle atrophy	May not be marked (may occur late and will be due to disuse)	Will be early and severe and due to denervation
Fasciculations and fibrillations	Do not occur	Are common

Sensory Disorders

Interruption of ascending pathways carrying various sensations results in loss of sensory perception ***(anesthesia)*** over parts of the body concerned. Reduced perception of touch is ***hypoesthesia***; reduced perception of pain is ***hypoalgesia***. Increased perception of touch is ***hyperesthesia***. Abnormal sensations are referred to as ***paresthesias***.

Referred Pain

It sometimes happens that when one of the viscera is diseased, pain is not felt in the region of the organ itself, but is felt in some part of the skin and body wall. This phenomenon is called ***referred pain.*** This pain is usually (but not always) referred to areas of skin supplied by the same spinal segments which innervate the viscus. Some classical examples of referred pain are given below:

- Pain arising in the diaphragm, or diaphragmatic pleura is referred to the shoulder (C4).
- Pain arising in the heart is referred to the lower cervical and upper thoracic segments. It is felt in the chest wall and along the medial side of the left arm (T1 to T2). It may also be referred to the neck or jaw.
- Referred pain from the stomach is felt in the epigastrium (T7 to T9) and that from the small intestines is felt in the epigastrium and around the umbilicus (T7 to T10). Pain from the appendix is felt in the umbilical region (T10). Large intestinal pain is referred to umbilical and hypogastric region (T10 to L1).
- Pain from the gall bladder is referred to the epigastrium. It may also be referred to the back just below the inferior angle of the right scapula (T7).
- Pain from uterus is felt at hypogastrium and inner border of thigh (L1, L2).
- Pain from cervix and pelvic viscera are felt in low back (S2 to S4).
- Pain arising in the area of distribution of one division of the trigeminal nerve may be referred along other branches of the same division, or even along branches of other divisions.

Herpes zoster

The dorsal root ganglia (and the sensory ganglia of cranial nerves) can be infected with a virus called Herpes virus. Vesicles appear on the skin over the area of distribution of the nerve. The condition is highly painful. This condition is called as ***herpes zoste***r (shingles).

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Disorders of equilibrium

Inability to maintain the equilibrium of the body, while standing, or while walking, is referred to as ***ataxia.*** This may occur as a result of interruption of afferent proprioceptive pathways i.e. tracts in the posterior column and the spinocerebellar pathways (***sensory ataxia***). Lack of proprioceptive information can be compensated to a considerable extent by information received through the eyes. The defects are, therefore, much more pronounced with the eyes closed (***Romberg's sign***).

Cauda equina syndrome and conus medullaris syndrome

Sometimes, the terminal part of spinal cord or the cauda equina nerves may get compressed by an extradural tumour, prolapsed intervertebral disc or vertebral canal stenosis. The clinical presentation as to whether the conus medullaris is affected or the cauda equina is affected varies considerably. A comparison is given below (Table 6.6):

Table 6.6 | Differences between conus medullaris syndrome and cauda equina syndrome

Features	Conus medullaris syndrome	Cauda equina syndrome
Part affected	Conus medullaris containing sacral segments of the cord and may be lumbar nerves	Sacral nerve roots
Presentation	Both upper motor neuron and lower motor neuron type paralysis	Only lower motor neuron type of paralysis
Onset	Sudden	Gradual
Laterality	Bilateral	May be unilateral
Low back pain	Severe	Not severe
Root pain	Not severe	Severe
Anesthesia	Perianal region	Saddle anesthesia
Paralysis	Bilateral, upper motor neuron type with exaggerated tendon reflexes, increased tone below the level of lesion and lower motor neuron type paralysis at the level of lesion	Unilateral, lower motor neuron type paralysis with hypotonia, loss of reflexes and atrophy of muscles
Bladder and bowel involvement	Early; urinary retention with overflow urinary and bowel incontinence	Late; urinary and bowel retention
Sexual dysfunction	More frequent	Less frequent

Other lesions of spinal cord

The spinal cord can get affected by:
- Congenital lesions, e.g. tethered cord syndrome, spina bifida
- Trauma, e.g. vertebral fracture, prolapsed intervertebral disc which may lead to complete transection of the cord or hemisection of the cord (Brown-Sequard syndrome)
- Vascular occlusion, e.g. anterior spinal artery syndrome
- Infection, e.g. poliomyelitis, viral transverse myelitis, tabes dorsalis
- Tumours (extradural, extramedullary or intramedullary), e.g. meningioma, lipoma
- Nutritional deficiencies, e.g. subacute combined degeneration
- Degenerative, demyelinating disorders, e.g. multiple sclerosis, motor neuron disease, syringomyelia

Whatever is the cause, the clinical signs are based on which tracts and nuclei of spinal cord are affected.

The anatomical basis of the clinical signs and symptoms in some of the above-mentioned conditions are given below:

Complete transection of the cord

- Involvement of corticospinal tracts of both sides will result in upper motor neuron type of paralysis below the level of lesion on both sides. It may be quadriplegia or paraplegia depending on the level.
- Involvement of all sensory tracts will result in total anaesthesia below the level.
- Loss of voluntary bladder and bowel control
- If the level is above C3, cessation of both automatic and volitional breathing i.e. death

Hemisection of the cord (Brown-Séquard syndrome) (Figure 6.15A)

- Involvement of spinothalamic tract causes contralateral loss of pain and temperature sensations below the level.
- Involvement of posterior column results in ipsilateral loss of fine touch, two point discrimination, joint position, and vibration sense.
- Involvement of corticospinal tract results in ipsilateral upper motor neuron type of paralysis below the level.

Anterior spinal artery syndrome (Figure 6.15B)

Thrombosis in the anterior spinal artery produces a characteristic syndrome involving the anterior two-thirds of the spinal cord.

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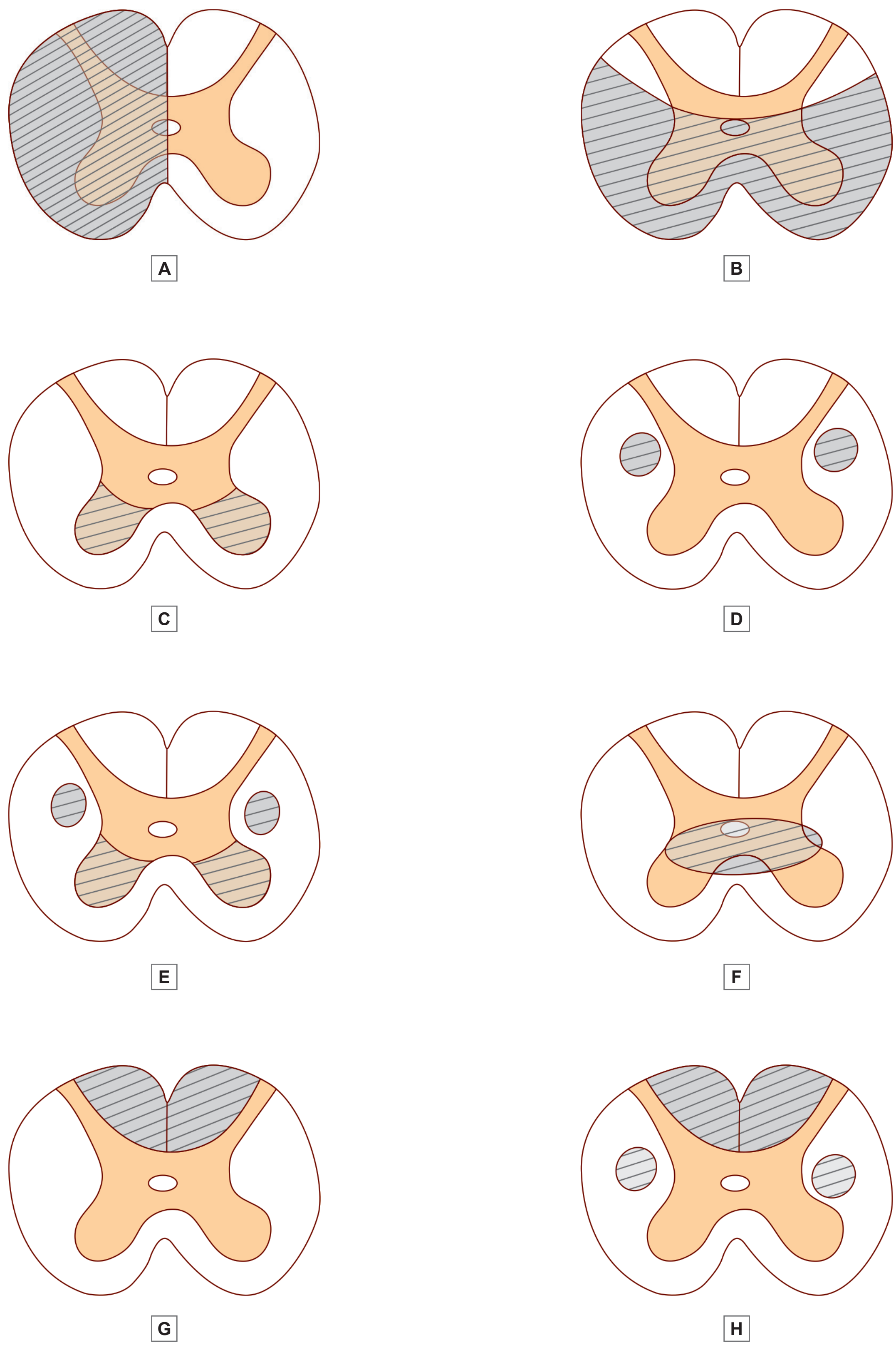

Fig. 6.15: Schematic representation of various lesions of spinal cord. **A.** Hemisection of the cord (Brown-Séquard syndrome); **B.** Anterior spinal artery syndrome; **C.** Lower motor neuron disease; **D.** Upper motor neuron disease; **E.** Combined upper and lower motor neuron paralysis; **F.** Syringomyelia; **G.** Sensory neuron disease; **H.** Combined dorsal and lateral column disease

Contd...

- The territory of supply includes the corticospinal tracts. This leads to an upper motor neuron paralysis below the level of lesion.
- The spinothalamic tracts are also involved. This leads to loss of sensations of pain and temperature below the level of lesion.
- Touch and conscious proprioceptive sensations are not affected as the posterior column tracts are not involved. The extent of damage varies depending on the efficiency of anastomoses in the region.

Lower motor neuron disease (Figure 6.15 C)

Lesion of ventral grey column neurons as in poliomyelitis or as in progressive muscular atrophy results in lower motor neuron paralysis of the affected segments.

Upper motor neuron disease (Figure 6.15 D)

Disease of the pyramidal tracts causes progressive upper motor neuron paralysis of the muscles from distal to proximal level.

Combined upper and lower motor neuron paralysis (Figure 6.15 E)

A combination of lesions of pyramidal tracts and anterior horn cells results in both UMN and LMN signs as in motor neuron disease (MND) or amyotrophic lateral sclerosis.

Syringomyelia (Figure 6.15 F)

A destructive process around the central canal of the spinal cord results in increase in the size of the cavity and affects the crossing spinothalamic fibres in the anterior white commissure. So there will be bilateral loss of pain and temperature sensations but the posterior column sensations are preserved as they do not get affected initially. This produces **"*dissociated anesthesia*."**

Sensory neuron disease (Figure 6.15 G)

Involvement of posterior columns, as in hereditary sensory neuropathy or syphilis causes bilateral loss of fine touch, two point discrimination, joint position, and vibration sense.

Combined dorsal and lateral column disease (Figure 6.15 H)

Involvement of both posterior columns and pyramidal tracts is seen in subacute combined degeneration due to vitamin B12 deficiency. This causes bilateral loss of fine touch, two point discrimination, joint position, and vibration sense and bilateral UMN paralysis.

Multiple Choice Questions

1. The somatic efferent cells of the ventral grey column of spinal cord are known as
   A. Alpha motor neurons
   B. Ganglion cells
   C. Gamma motor neurons
   D. Renshaw cells
2. The fibres of posterior spinocerebellar tract arise from
   A. Visceral afferent nucleus
   B. Substantia gelatinosa
   C. Nucleus dorsalis
   D. Nucleus proprius
3. The lower motor neurons are located in the
   A. Dorsal root ganglion
   B. Pontine nuclei
   C. Sympathetic chain
   D. Anterior grey column of the spinal cord
4. Which of the following is the most posterior in the dorsal grey column of the spinal cord?
   A. Substantia gelatinosa (of Rolando)
   B. Nucleus dorsalis (Clark's column)
   C. Nucleus proprius
   D. Visceral afferent nucleus

Answers

1. A **2.** C **3.** D **4.** A

Chapter 7

Brainstem – External Features

Specific Learning Objectives

At the end of learning, the student shall be able to:
- Specify the structures forming the brainstem
- Describe the external features of medulla oblongata, pons and midbrain
- Specify the site of attachment of lower ten cranial nerves
- Specify the blood supply of medulla oblongata, pons and midbrain.

INTRODUCTION

The brainstem consists of the midbrain, pons, and medulla from above downwards (Figure 7.1).

Superiorly, the brainstem (midbrain) is continuous with the structures forming the forebrain—thalamus, hypothalamus, and cerebral hemispheres (Figure 7.2). Inferiorly, it is continuous with the spinal cord (Figure 7.1).

Posteriorly, the pons and medulla are separated from the cerebellum by the fourth ventricle (Figure 7.2). The ventricle is continuous below with the central canal, which traverses the lower part of the medulla and becomes continuous with the central canal of the spinal cord. Cranially, the fourth ventricle is continuous with the aqueduct, which passes through the midbrain (Figure 7.2).

The midbrain, pons, and medulla are connected to the cerebellum posteriorly by the superior, middle, and inferior cerebellar peduncles, respectively (Figure 7.3).

A number of cranial nerves are attached to the brainstem. The third and fourth nerves emerge from the surface of the midbrain and the fifth, from the pons. The sixth, seventh, and eighth nerves emerge at the junction of the pons and medulla. The ninth, tenth, eleventh, and twelfth cranial nerves emerge from the surface of the medulla (Figure 7.1 and Table 7.1).

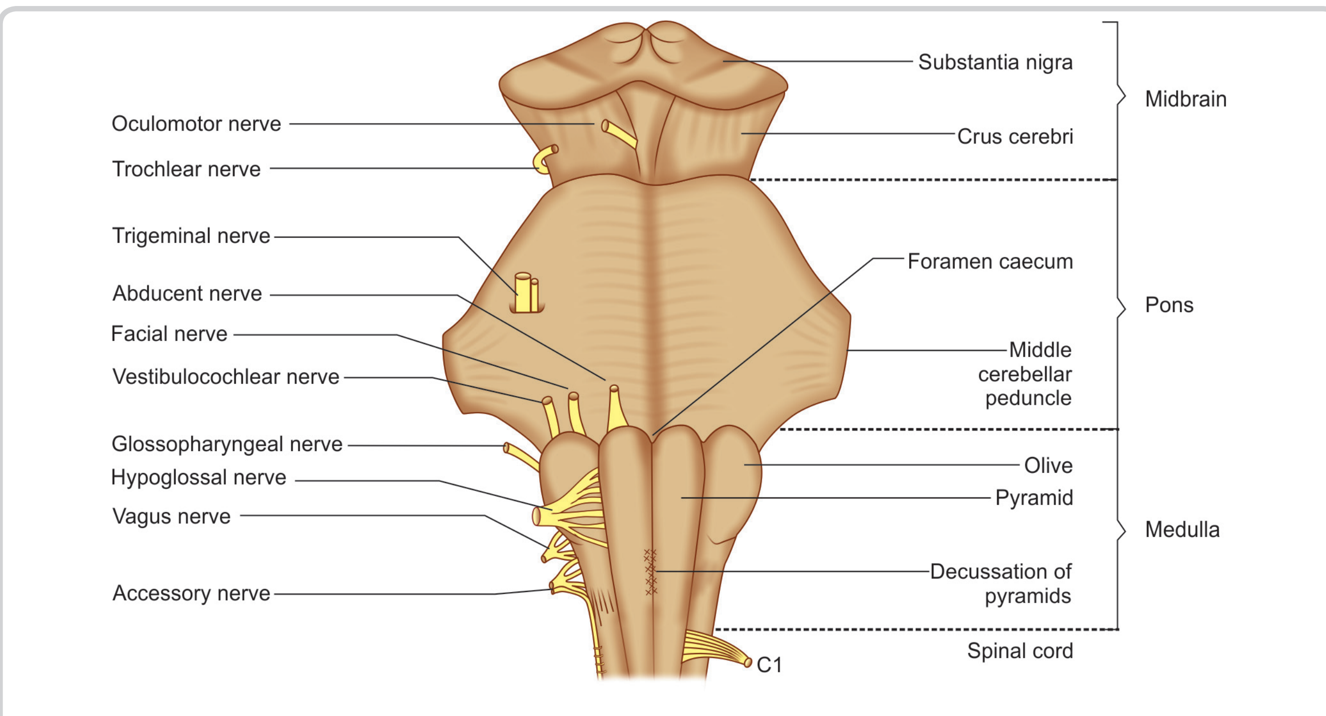

Figure 7.1: Ventral aspect of the brainstem

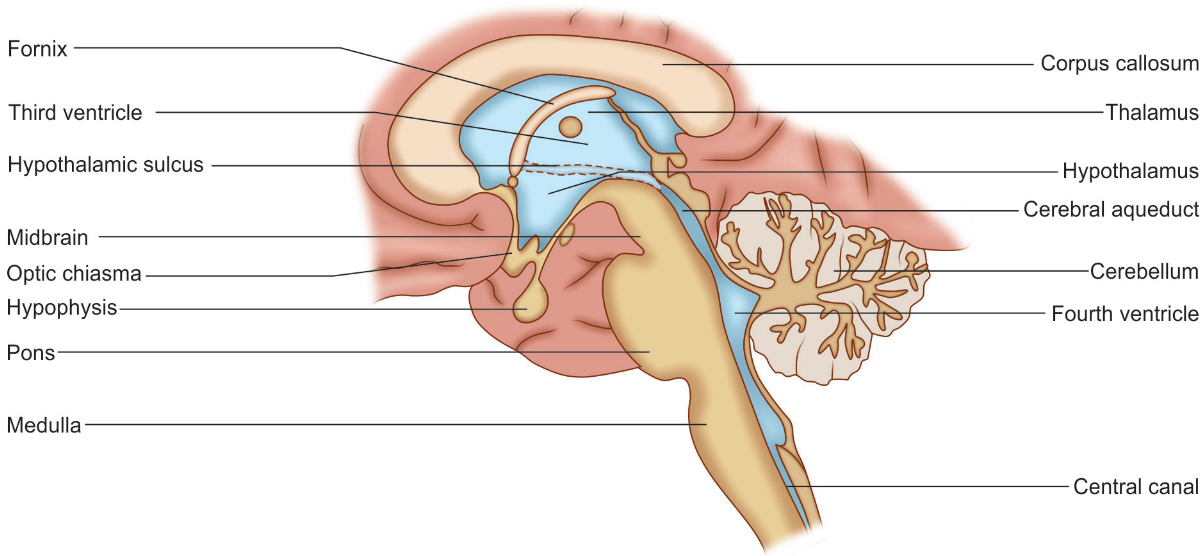

Figure 7.2: Midsagittal section of the brain showing midbrain, pons, and medulla. Note that pons and medulla are separated from the cerebellum by the fourth ventricle

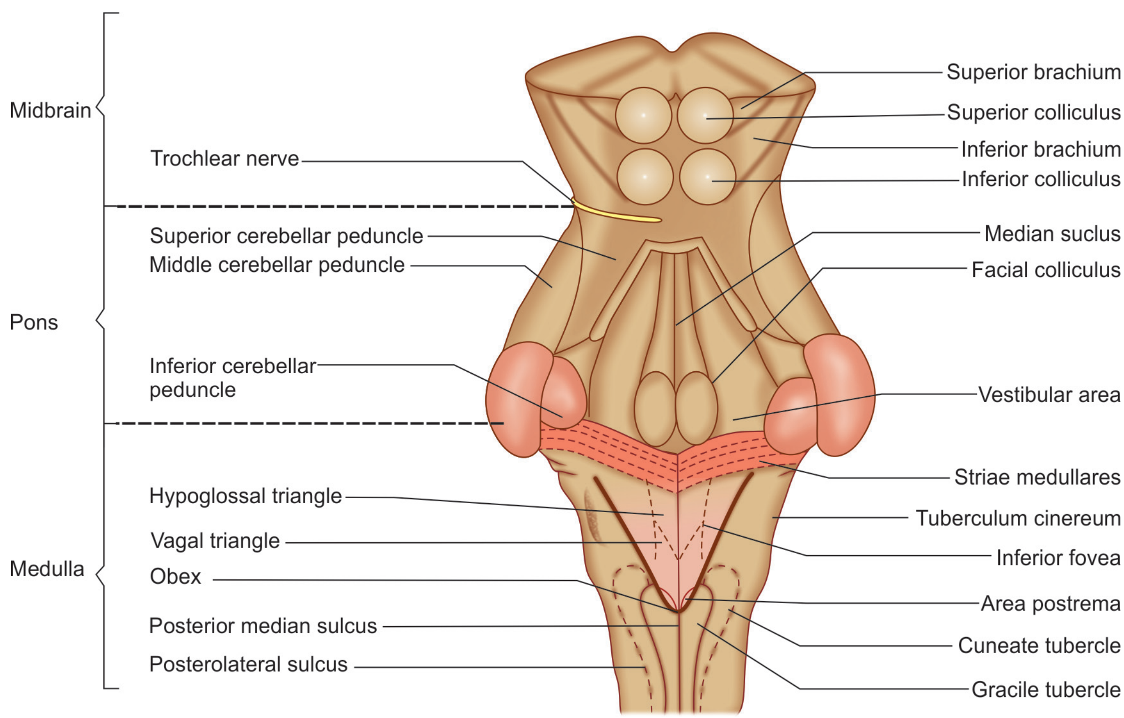

Figure 7.3: Dorsal aspect of the brainstem

EXTERNAL FEATURES OF MEDULLA OBLONGATA

The medulla is broad above where it joins the pons and narrows down below where it becomes continuous with the spinal cord. Its length is about 3 cm, and its width is about 2 cm at its upper end. The junction of the medulla and the spinal cord lies at the level of the upper border of the atlas vertebra. The transition is, in fact, not abrupt but occurs over a certain distance.

Table 7.1 | Attachment of Cranial Nerves

Site of attachment	Cranial nerves
Forebrain	I and II
Midbrain	III and IV
Hindbrain	
Pons	V
Junction of pons and medulla	VI–VIII
Medulla	IX–XII

The medulla is divided into a lower closed part, which surrounds the central canal and an upper open part, which is related to the lower part of the fourth ventricle (Figure 7.4).

The surface of the medulla is marked by a series of fissures or sulci that divide it into a number of regions. The ***anterior median fissure*** and the ***posterior median sulcus*** are upward continuations of the corresponding features seen in the spinal cord. Where the anterior median fissure meets the pontomedullary junction, there is a depression called as foramen caecum. Each half of the medulla is marked by two sulci, the anterolateral and posterolateral sulci which are continuations of the corresponding sulci of the cord. The ***anterolateral sulcus*** lies in line with the ventral roots of spinal nerves. The rootlets of the hypoglossal nerve emerge from this sulcus. The ***posterolateral sulcus*** is in line with the dorsal nerve roots of spinal nerves and gives attachment to rootlets of the glossopharyngeal, vagus, and accessory nerves. The anterolateral and posterolateral sulci with nerve roots divide the surface of each half of the medulla oblongata into anterior, posterior, and lateral regions like that in the spinal cord.

Anterior (Ventral) Aspect

- ***Pyramid:*** The region between the anterior median fissure and the anterolateral sulcus is occupied (on either side of the midline) by an elevation called the ***pyramid*** (Figure 7.1). The elevation is caused by a large bundle of fibres that descend from the cerebral cortex to the spinal cord. Some of these fibres cross from one side to the other in the lower part of the medulla, obliterating the anterior median fissure. These crossing fibres constitute the ***decussation of the pyramids***.

  Some other fibres emerge from the anterior median fissure, above the decussation and wind laterally over the surface of the medulla. These are the ***anterior external arcuate fibres***.
- ***Olive:*** In the upper part of the medulla, the region between the anterolateral and posterolateral sulci shows a prominent, elongated, oval swelling, named the ***olive***. This swelling is about half an inch long. It is produced by a large mass of grey matter called the ***inferior olivary nucleus*** (Figures 7.1 and 7.5).
- ***Rootlets of the hypoglossal nerve:*** These emerge from the anterolateral sulcus between the pyramid and the olive (Figure 7.1).
- ***Inferior cerebellar peduncles*** of the left and right side attach the medulla with the cerebellum. They lie lateral to the posterolateral sulcus on each side. They also form the inferolateral boundaries of the lower half of fourth ventricle on the posterior aspect of the open part of medulla.
- ***Rootlets of the ninth, tenth, and eleventh (cranial part) cranial nerves:*** These emerge through the posterolateral sulcus separating the olive from the inferior cerebellar peduncle.

Posterior (Dorsal) Aspect

The posterior surface of the lower part (closed part) medulla (Figure 7.4), between the posterior median sulcus and the posterolateral sulcus, contains tracts that enter from the posterior funiculus of the spinal cord. These are the ***fasciculus***

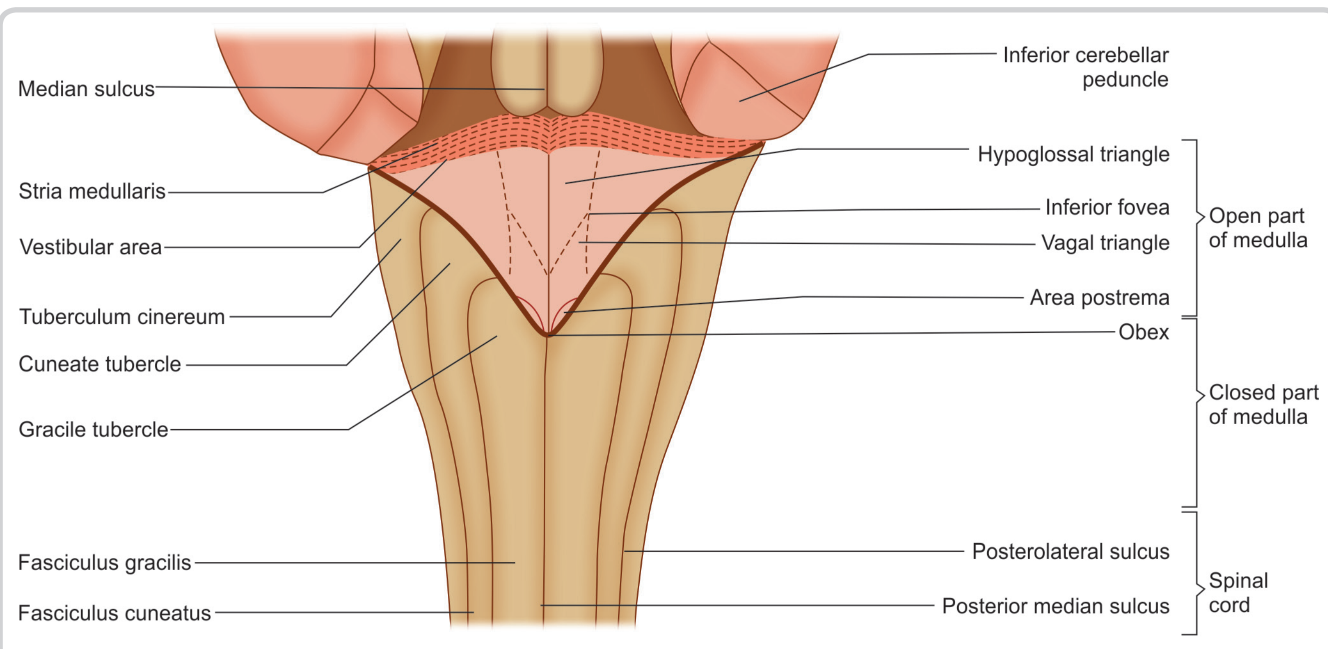

Figure 7.4: Schematic diagram to show the open and closed parts of medulla

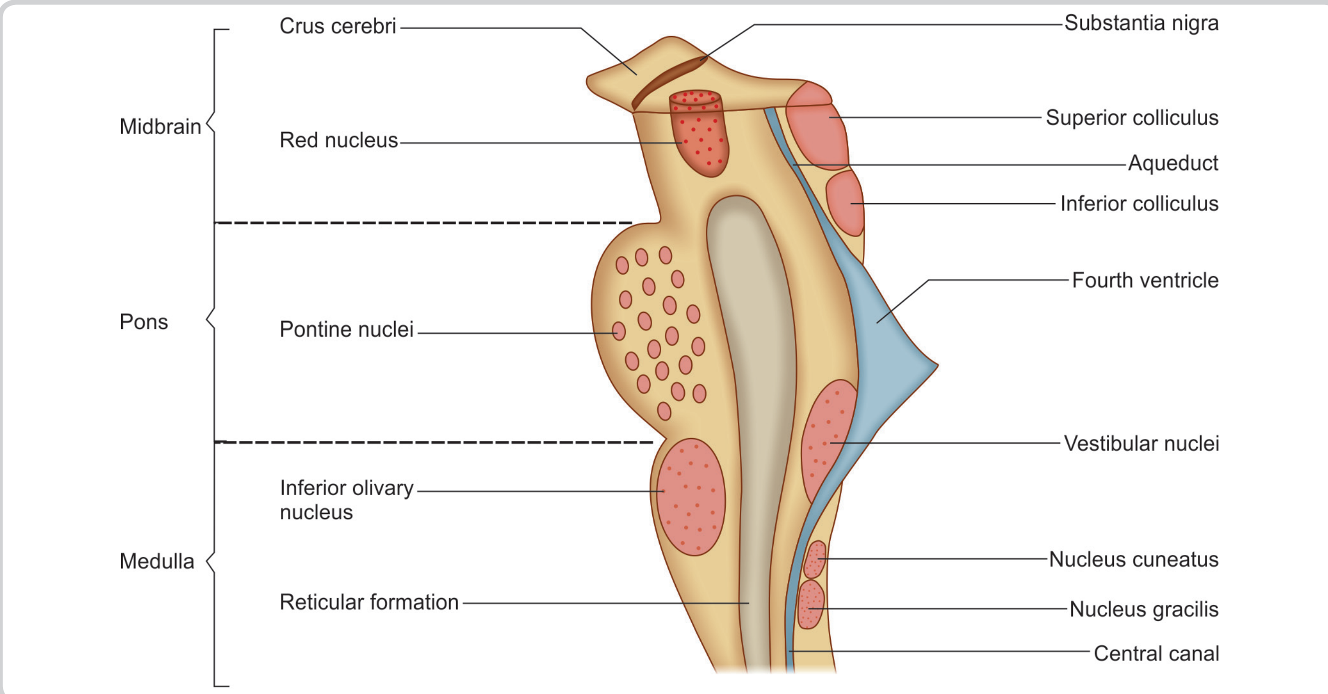

Figure 7.5: Median section through the brainstem. Some important masses of grey matter are shown projected on to median plane

gracilis, next to the midline, and the ***fasciculus cuneatus,*** placed laterally. These fasciculi end in rounded elevations called the ***gracile and cuneate tubercles***. These tubercles are produced by masses of grey matter called the ***nucleus gracilis*** and the ***nucleus cuneatus,*** respectively (Figure 7.5).

The lower part of the medulla, immediately lateral to the fasciculus cuneatus, is marked by another longitudinal elevation called the ***tuberculum cinereum***. This elevation is produced by an underlying collection of grey matter of the ***spinal nucleus of the trigeminal nerve***. The grey matter of this nucleus is covered by a layer of nerve fibres that form the ***spinal tract of the trigeminal nerve***.

The posterior surface of the upper medulla (open part) forms the lower part of the floor of the fourth ventricle. This fossa is bounded on either side by the inferior cerebellar peduncles. The features of this part of medulla is described further in chapter 17.

BLOOD SUPPLY OF MEDULLA OBLONGATA

The medulla is supplied by various branches of the vertebral arteries. These are the ***anterior and posterior spinal arteries, the posterior inferior cerebellar artery, and small direct branches*** (Figure 7.6). The anterior spinal artery supplies a triangular area next to the midline. This area includes the pyramid, the medial lemniscus, and the hypoglossal nucleus. The posterior spinal artery supplies a small area including the gracile and cuneate nuclei. The posterior inferior cerebellar artery supplies the retro-olivary region, i.e. the dorsolateral part of medulla oblongata. This region contains several important structures including the spinothalamic tracts, the rubrospinal tract, the nucleus ambiguus, the dorsal vagal nucleus, and descending autonomic fibres. The posterior inferior cerebellar artery also supplies part of the inferior cerebellar peduncle. The rest of the medulla is supplied by direct bulbar branches of the vertebral arteries.

EXTERNAL FEATURES OF PONS

Pons is a part of the brainstem, situated between the medulla below and midbrain above (Figures 7.1 to 7.3).

It lies in the posterior cranial fossa on the clivus, anterior to the cerebellum.

Pons, in a literal sense, means *"the bridge"*. It is so named because it acts as a conduit for the passage of

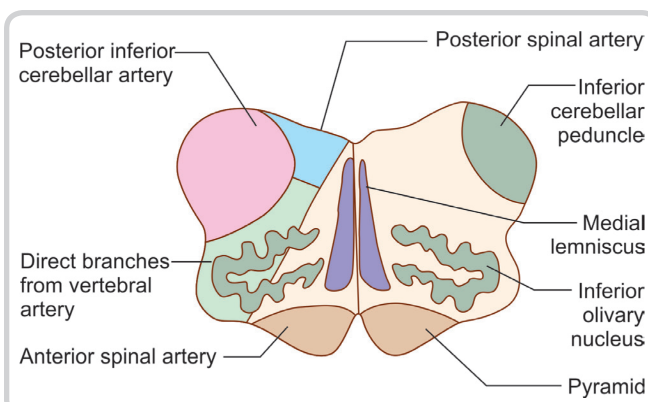

Figure 7.6: Cross section through the medulla to show the regions supplied by different arteries

fibres from one side of the cerebellum to the other by its transverse fibres constituting the middle cerebellar peduncle as well as vertically between the medulla below, and midbrain above. Pons is important physiologically, as the centre of respiration is present in it. Nuclei of the cranial nerves, V (trigeminal), VI (abducent), VII (facial), and VIII (vestibulocochlear) lie in the pons.

Anterior Aspect

Pons shows a convex anterior surface, marked by prominent transversely running fibres. Laterally, these fibres collect to form a bundle, the ***middle cerebellar peduncle***.

The ***trigeminal nerve*** emerges from the anterior surface and the point of its emergence is taken as a landmark to define the plane of junction between the pons and the middle cerebellar peduncle.

The anterior surface of the pons is marked, in the midline, by a shallow groove, the ***sulcus basilaris***, which lodges the basilar artery.

The line of junction between the pons and the medulla is marked by a groove through which a number of cranial nerves emerge. The abducent nerve emerges from just above the pyramid and runs upward in close relation to the anterior surface of the pons. The facial and vestibulocochlear nerves emerge from the interval between the olive and the pons.

Posterior Aspect

The posterior aspect of the pons forms the upper part of the floor of the fourth ventricle. More feature of this part are described in chapter 17.

On either side of the lower part of the pons, there is a region called the ***cerebellopontine angle***. This region lies near the lateral aperture of the fourth ventricle. The facial, vestibulocochlear, and glossopharyngeal nerves, the nervus intermedius, and sometimes, the labyrinthine arteries lie in this region.

BLOOD SUPPLY OF PONS

The pons is supplied by branches from the ***basilar artery***. The ***medial portion*** of the ventral part of the pons is supplied by ***paramedian branches***. The ***lateral portion of the ventral part*** is supplied by ***short circumferential branches***. The ***dorsal part of the pons*** is supplied by ***long circumferential branches***. The dorsal part also receives branches from the ***anterior inferior cerebellar*** and ***superior cerebellar arteries***. The paramedian branches of the basilar artery may extend into this region from the ventral part of the pons.

EXTERNAL FEATURES OF MIDBRAIN

The midbrain is the uppermost part of the brainstem, connecting the pons and cerebellum with the forebrain. It is about 2 cm in length. Its cavity, the cerebral aqueduct, connects the third ventricle to the fourth ventricle (Figure 7.2).

The midbrain contains nuclei of origin for cranial nerves III (oculomotor) and IV (trochlear). Apart from the cranial nerve nuclei, the midbrain also has nuclei that coordinate the movement of the eyeball in response to visual stimuli which is located at the level of superior colliculi (Figure 7.3). Nuclei, which coordinate movements of head and trunk in response to auditory stimuli are located at the level of inferior colliculi (Figure 7.3).

Anterior Aspect

When the midbrain is viewed from the ***anterior aspect***, two large bundles of fibres are seen, one on each side of the midline. These are the ***cerebral peduncles***. They are separated by a deep fissure. Near the pons, the fissure is narrow, but broadens as the peduncles diverge to enter the corresponding cerebral hemispheres. The parts of the peduncles just below the cerebrum, form the posterior boundary of a space called the ***interpeduncular fossa*** (Figure 12.18). The oculomotor nerve emerges from the medial aspect of the peduncle of the same side.

Posterior Aspect

The posterior aspect of the midbrain is marked by four rounded swellings (Figure 7.3). These are the ***colliculi***, a pair of superior colliculi and a pair of inferior colliculi on each side. These are also known as corpora quadrigemina. Each colliculus is related laterally to a ridge called the ***brachium***. The ***superior brachium*** (also called the superior quadrigeminal brachium or brachium of superior colliculus) connects the superior colliculus to the lateral geniculate body. Similarly, the ***inferior brachium*** (also called the inferior quadrigeminal brachium or brachium of inferior colliculus) connects the inferior colliculus to the medial geniculate body. Just below the colliculi, there is the uppermost part of a membrane, the ***superior medullary velum***, which stretches between the two superior cerebellar peduncles and helps to form the roof of the fourth ventricle. The trochlear nerve emerges from the velum and then winds round the side of the midbrain to reach its ventral aspect.

Note: The trochlear nerve is the only cranial nerve that emerges from the dorsal aspect of the brainstem.

BLOOD SUPPLY OF MIDBRAIN

The midbrain is supplied mainly by branches of the ***basilar artery***. These are the ***posterior cerebral*** and ***superior cerebellar arteries*** and ***direct branches*** from the basilar artery. Branches are also received from the ***posterior communicating*** and ***anterior choroidal arteries***. Branches arising from these vessels may either be paramedian, which supply parts near the midline or circumferential which wind round the midbrain to supply lateral and dorsal parts. One of the latter arteries is called the ***quadrigeminal artery***. It is the main source of blood to the colliculi.

Multiple Choice Questions

1. The cranial nerve that emerges from the medulla oblongata between the pyramid and the olive is
   A. Glossopharyngeal
   B. Vagus
   C. Cranial accessory
   D. Hypoglossal

2. The cranial nerve that emerges lateral to the olive is
   A. Abducent
   B. Spinal accessory
   C. Glossopharyngeal
   D. Hypoglossal

3. The structure that lie deep to tuberculum cinereum is
   A. Nucleus gracilis
   B. Spinal nucleus of trigeminal
   C. Nucleus coeruleus
   D. Hypoglossal nucleus

4. One of the cranial nerves that lie at the cerebellopontine angle is
   A. Vestibulocochlear
   B. Trochlear
   C. Trigeminal
   D. Accessory

5. To which structure does the superior brachium connect the superior colliculus?
   A. Medial geniculate body
   B. Cerebellum
   C. Lateral geniculate body
   D. Pulvinar

6. The dorsolateral part of medulla oblongata is supplied by which of the following arteries?
   A. Posterior spinal
   B. Basilar
   C. Superior cerebellar
   D. Posterior inferior cerebellar

Answers

1. D **2.** C **3.** B **4.** A **5.** C **6.** D

Chapter 8

Brainstem – Internal Features

Specific Learning Objectives

At the end of learning, the student shall be able to:
- Describe the internal features of medulla oblongata
- Draw and label transverse sections (TS) of medulla oblongata at pyramidal decussation, at sensory decussation and at midolivary levels
- Describe the anatomical basis of clinical syndromes affecting medulla oblongata
- Describe the internal features of pons
- Draw and label TS of lower pons at the level of facial colliculus and TS upper pons at the level of trigeminal nucleus
- Describe the anatomical basis of clinical syndromes affecting pons
- Describe the internal features of midbrain
- Draw and label TS of midbrain at the level of superior colliculi and at the level of inferior colliculi
- Describe the anatomical basis of clinical syndromes affecting midbrain
- Describe the extent, some important nuclei, connections and functions of reticular formation

MEDULLA OBLONGATA

The arrangement of grey and white matter in the lowermost part of medulla is similar to that of spinal cord. However, above this, its internal structure changes gradually. The change in the arrangement of grey and white matter in the upper part of the medulla is mainly due to the presence of the fourth ventricle.

The internal structure of medulla is generally studied at the following levels (Figure 8.1 A, B and C):
- At the level of the pyramidal decussation
- At the level of the sensory decussation
- At the level of the olivary nucleus

SECTION THROUGH MEDULLA OBLONGATA AT THE LEVEL OF PYRAMIDAL DECUSSATION

A section at the level of the pyramidal decussation (Figure 8.1A) shows some similarity to sections through the spinal cord.

The ***central canal*** is surrounded by ***central grey matter***. The ***ventral grey columns*** are present but are separated from the central grey matter by the ***decussating pyramidal fibres***.

The neurons in the ventral grey column give origin to the uppermost rootlets of the first cervical nerve and to some fibres in the spinal root of the accessory nerve. The area between the ventral grey column and the spinal nucleus of the trigeminal nerve is occupied by a network of fibres and scattered nerve cells called ***reticular formation***.

The region behind the central grey matter is occupied by the ***fasciculus gracilis*** medially and by the ***fasciculus cuneatus*** laterally. Closely related to these fasciculi, there are two tongue-shaped extensions of the central grey matter. The medial of these extensions is the ***nucleus gracilis*** and the lateral is the ***nucleus cuneatus***. More laterally, there is the ***spinal nucleus of the trigeminal nerve***. When traced inferiorly, this nucleus reaches the second cervical segment of the spinal cord, where it becomes continuous with the substantia gelatinosa. Above, the nucleus extends as far as the upper part of the pons. The spinal nucleus of the trigeminal nerve is related superficially to the ***spinal tract*** of the trigeminal nerve.

The main descending fibres seen at this level are the corticospinal fibres, on their way from the cerebral cortex to the spinal cord. At this level in the medulla, many of these fibres run backwards and medially to cross in the midline. These crossing fibres constitute the ***decussation of the pyramids.*** After crossing the midline, these fibres turn downwards in the region lateral to the central grey matter to form the ***lateral corticospinal tract***.

Those fibres of the pyramids that do not cross, descend into the ventral funiculus of the spinal cord to form the ***ventral corticospinal tract***.

Other descending tracts seen at this level (in the anterolateral part of the medulla, Figure 8.2, right half) are:
- Rubrospinal tract
- Vestibulospinal tract
- Olivospinal tract and

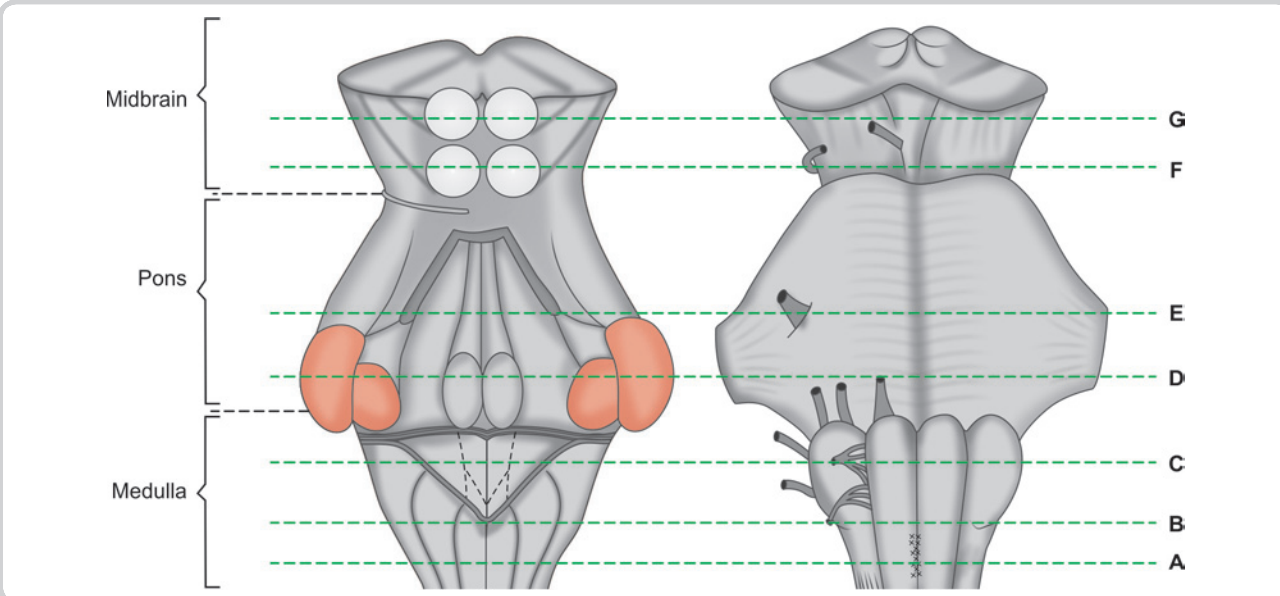

Figure 8.1: Posterior and anterior aspects of brainstem to show the levels of transverse sections (A to G) taken to study its internal features

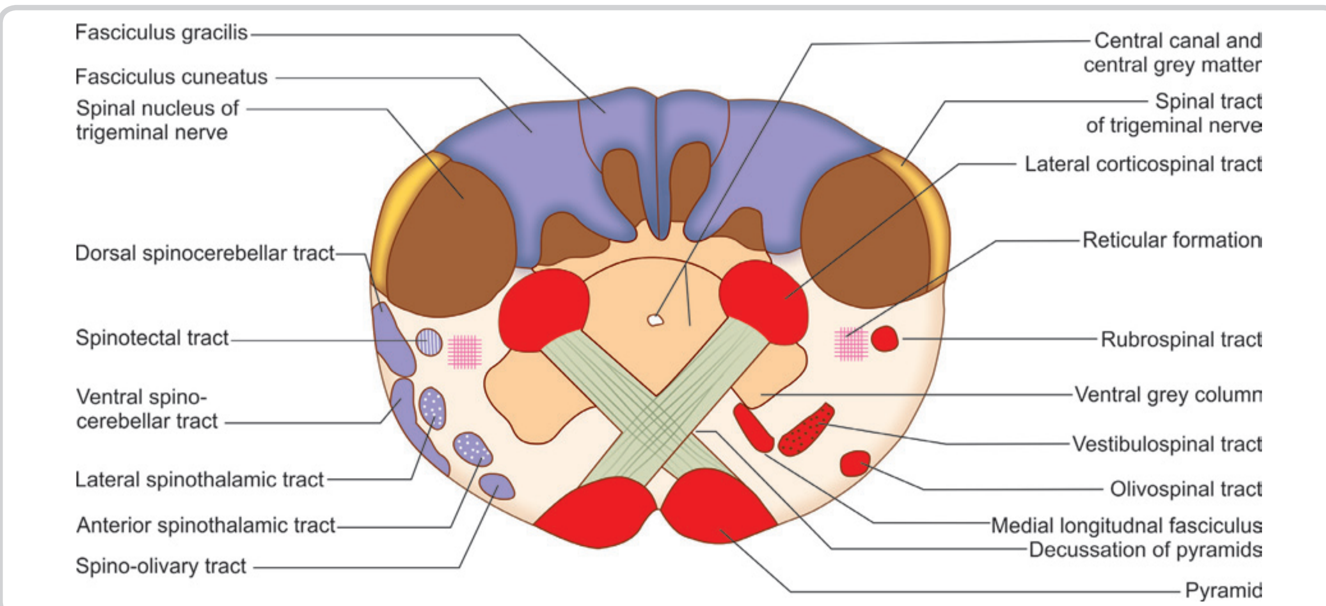

Figure 8.2: Transverse section through the medulla at the level of the pyramidal decussation

- Tectospinal tract

The tectospinal tract is incorporated within the medial longitudinal fasciculus.

Among the descending tracts may also be included the spinal tract of the trigeminal nerve, which forms a layer of fibres superficial to the spinal nucleus of this nerve.

The ***ascending tracts*** seen at this level include (Figure 8.2, left half):

- Fasciculus gracilis and fasciculus cuneatus (which occupy the areas behind the corresponding nuclei)
- Spinothalamic tract
- Spinocerebellar tract
- Spinotectal tract
- Spino-olivary tract

SECTION THROUGH MEDULLA OBLONGATA AT THE LEVEL OF SENSORY DECUSSATION (LEMNISCAL DECUSSATION)

This level lies a little above the level of the pyramidal decussation (Figure 8.1B).

The central canal is surrounded by the central grey matter. The nucleus gracilis, the nucleus cuneatus, the spinal nucleus of the trigeminal nerve, and the pyramids occupy the same positions as at lower levels.

The nucleus gracilis and the nucleus cuneatus are, however, much larger and are no longer continuous with the central grey matter. Internal arcuate fibres arising in these nuclei arch ventrally and medially around the central grey matter to cross the midline. These crossing fibres constitute the ***lemniscal (or sensory) decussation***. After crossing the midline, these fibres turn cranially to constitute the ***medial lemniscus***. As the fibres from the nucleus gracilis and the nucleus cuneatus pass ventrally, they cross each other so that the fibres from the nucleus gracilis come to lie ventral to those from the nucleus cuneatus. The most medial fibres (from the legs) lie most anteriorly in the medial lemniscus. These are followed by fibres from the trunk and upper limb in that order. At higher levels in the brainstem, the medial lemniscus changes its orientation; its long axis (as seen in cross section) becoming transverse (Figure 8.12). The most anterior fibres become lateral and the posterior fibres become medial. In its course through the medulla, the medial lemniscus is joined by the anterior spinothalamic tract.

Fibres in the medial lemniscus are arranged in layers corresponding to spinal segments; those from segment C1 are most medial and those from S4 are most lateral.

The ***accessory cuneate nucleus*** is placed dorsolateral to the cuneate nucleus. It receives proprioceptive impulses from the upper limb through fibres arising in spinal grey matter of cervical segments of the cord. Efferents of the accessory cuneate nucleus constitute the ***posterior external arcuate fibres***. They reach the cerebellum through the inferior cerebellar peduncle of the same side.

A number of cranial nerve nuclei can be identified at this level. Several of these are present in relation to the central grey matter. The hypoglossal nucleus is located ventral to the central canal just lateral to the midline. The dorsal vagal nucleus lies dorsolateral to the hypoglossal nucleus. The nucleus of the solitary tract is seen dorsal to the central canal near the midline. The lower ends of these nuclei become continuous with each other to form the commissural nucleus of the vagus. The nucleus ambiguus lies in the reticular formation medial to the spinal nucleus of the trigeminal nerve.

Other masses of grey matter that may be recognized at this level are:

- The lowest part of the ***inferior olivary nucleus***
- ***Medial accessory olivary nucleus,*** which lies dorsal to the medial part of the inferior olivary nucleus
- ***Lateral reticular nucleus*** lying in the lateral part of the reticular formation
- ***Arcuate nuclei*** lying on the anterior aspect of the pyramids

The region lateral to the medial lemniscus contains scattered neurons mixed with nerve fibres. This region is the ***reticular formation***. More laterally, there is a mass of white matter containing various tracts.

The ascending tracts present at this level are (Figure 8.3, left half):

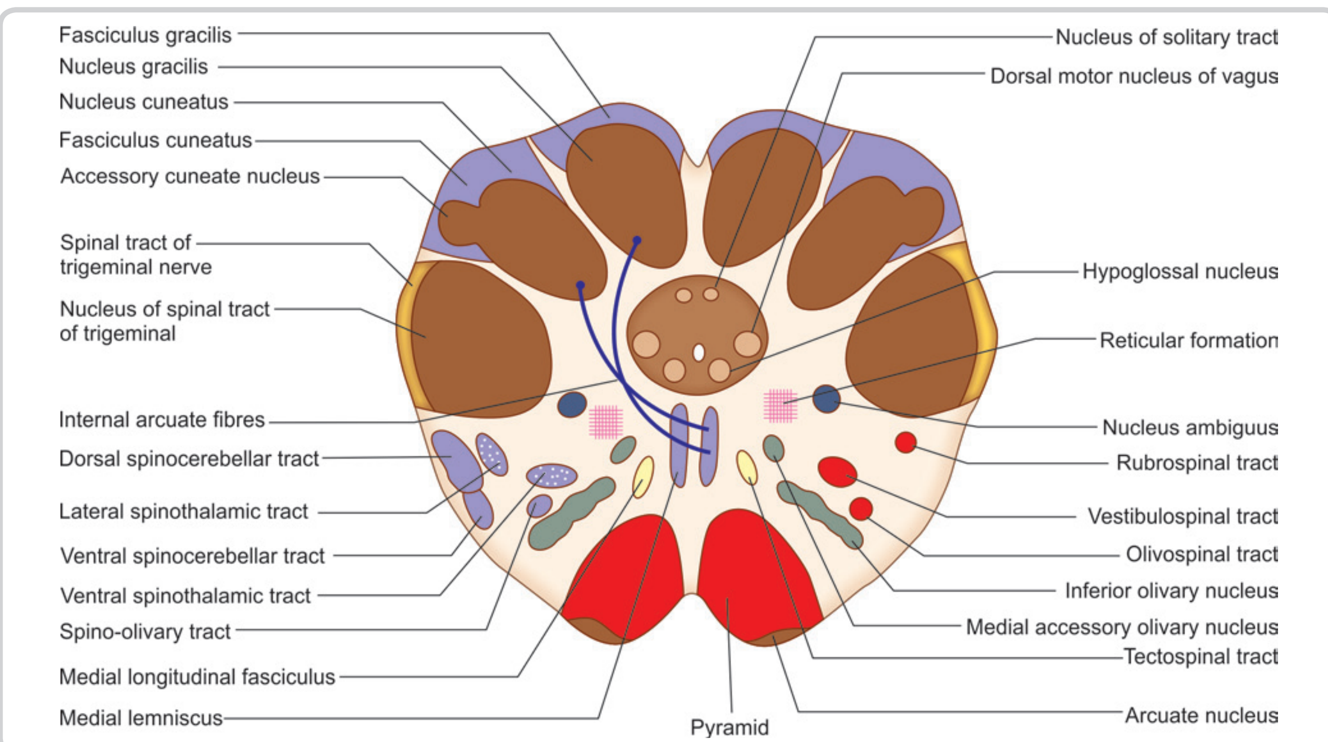

Figure 8.3: Transverse section through the medulla at the level of sensory decussation

- The gracile and cuneate fasciculi—these are much smaller than at lower levels, as the fibres of these tracts progressively terminate in the gracile and cuneate nuclei
- Spinothalamic tract
- Spinocerebellar tract
- Spinotectal tract and
- Spino-olivary tracts all of which lie in the anterolateral region

The descending tracts present are (Figure 8.3, right half):

- Pyramids
- Rubrospinal tract
- Vestibulospinal tract
- Olivospinal tract
- Medial longitudinal fasciculus, which includes the tectospinal tract

SECTION THROUGH MEDULLA OBLONGATA AT THE LEVEL OF OLIVE (MID-OLIVARY LEVEL) (FIGURE 8.1C)

A section through the medulla at the level of the olive is shown in Figure 8.4.

The pyramids, medial lemniscus, spinal nucleus and tract of the trigeminal nerve, and reticular formation are present in the same relative position as at lower levels. The medial lemniscus is, however, much more prominent and is somewhat expanded anteriorly. Lateral to the spinal nucleus (and tract) of the trigeminal nerve, a large compact bundle of fibres is seen. This is the ***inferior cerebellar peduncle,*** which connects the medulla to the cerebellum. Posteriorly, the medulla forms the floor of the fourth ventricle.

Several cranial nerve nuclei can be recognized in relation to the floor of the fourth ventricle (Figure 8.4). From medial to lateral side, these are the hypoglossal nucleus, the dorsal vagal nucleus, and the vestibular nuclei. The solitary tract and its nucleus lie ventrolateral to the dorsal vagal nucleus. The nucleus ambiguus is located much more ventrally within the reticular formation.

The dorsal and ventral cochlear nuclei are seen in relation to the inferior cerebellar peduncle. They are shown schematically in Figure 8.4. They are prominent at higher levels of the medulla, near its junction with the pons.

Other masses of grey matter present are the medial and dorsal accessory olivary nuclei (lying medial and dorsal, respectively, to the inferior olivary nucleus), the lateral reticular nucleus and arcuate nuclei, which occupy the same relative positions as at lower levels. The pontobulbar body lies on the dorsolateral aspect of the inferior cerebellar peduncle (Figure 8.4, right half).

The descending tracts seen at this level are (Figure 8.4, right half):

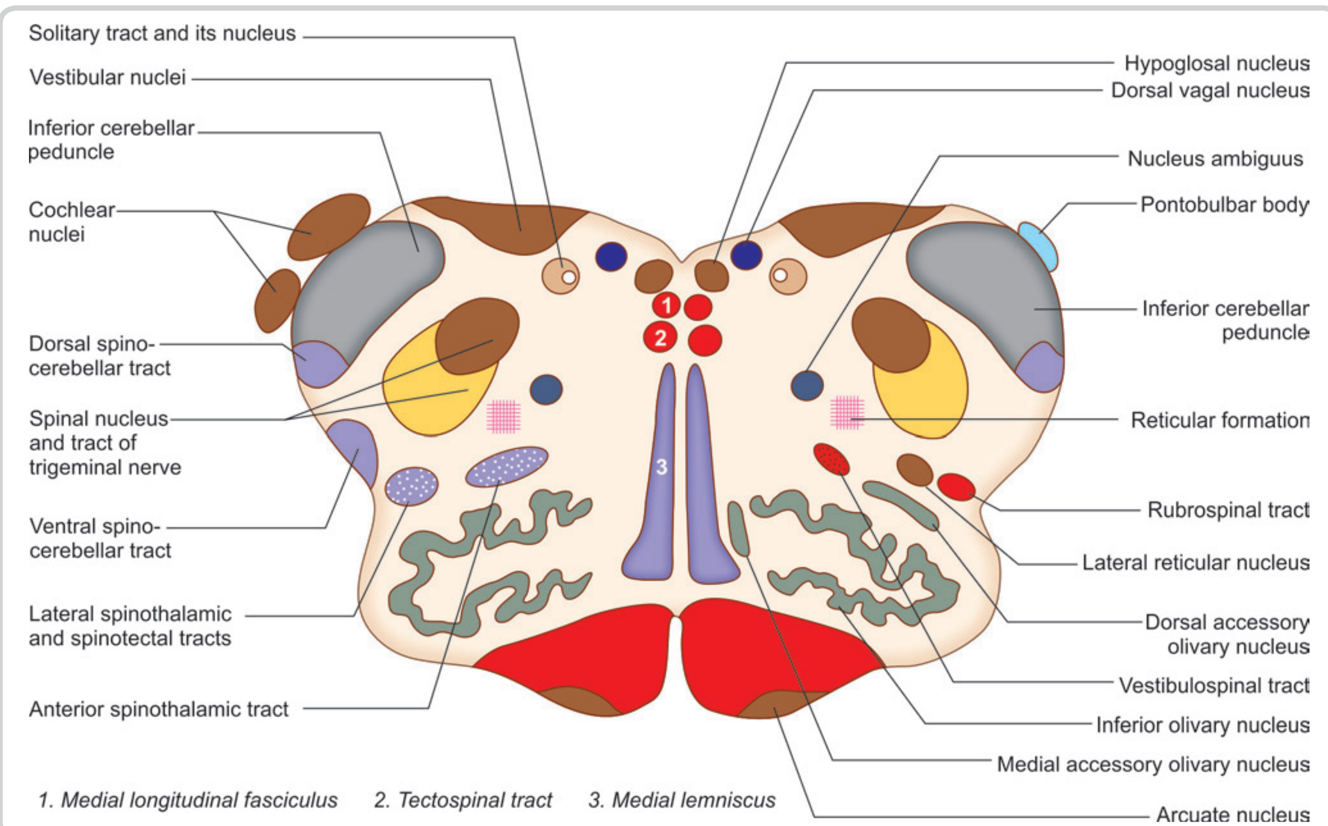

Figure 8.4: Transverse section through the medulla at the level of the olive

- Pyramids
- Tectospinal tract
- Vestibulospinal tract
- Rubrospinal tract
- Spinal tract of the trigeminal nerve

The ascending tracts seen at this level are (Figure 8.4, left half):

- Medial lemniscus, which forms an anteroposterior L-shaped band next to the midline
- Spinothalamic tract
- Spinocerebellar tract
- Spinotectal tract

At this level, the dorsal spinocerebellar tract lies within the inferior cerebellar peduncle. The ventral spinocerebellar tract lies more anteriorly near the surface of the medulla. The spinothalamic tracts lie dorsolateral to the inferior olivary nucleus. The medial longitudinal fasciculus lies dorsal to the medial lemniscus.

Clinical Correlation

Injury to medulla

Injury to the medulla is usually fatal because vital centres controlling the heart and respiration are located here. Paralysis due to a lesion in the medulla is called ***bulbar palsy***. In this condition, the ninth, tenth, eleventh and twelfth cranial nerves are affected. The tracts are closely packed as they pass through the brainstem; hence, lesions produce widespread effect. This may result in paralysis of the muscles on the opposite side (due to damage to the corticocospinal tract) and loss of sensation of the opposite side (due to damage to ascending sensory tracts).

Connections of the Inferior Olivary Complex

Afferent Fibres

The main afferents of the inferior olivary nucleus are from the cerebral cortex and the spinal cord (Figure 8.5).

Efferent Fibres

The main efferents are to the cerebellar cortex through olivocerebellar tract. The olivospinal tract is considered to be small or absent. The nucleus is a relay station on the cortico-olivocerebellar and spino-olivo-cerebellar pathways. Other connections of the nucleus are shown in Figure 8.5.

The ***accessory olivary nuclei*** are connected to the cerebellum by ***parolivo-cerebellar tract***.

Connections of Arcuate Nuclei and Pontobulbar Body

The ***arcuate nuclei*** are generally regarded as displaced pontine nuclei. Cortical fibres reach them through the pyramids. These nuclei relay to the cerebellum by fibres which follow two separate pathways. Some of them wind

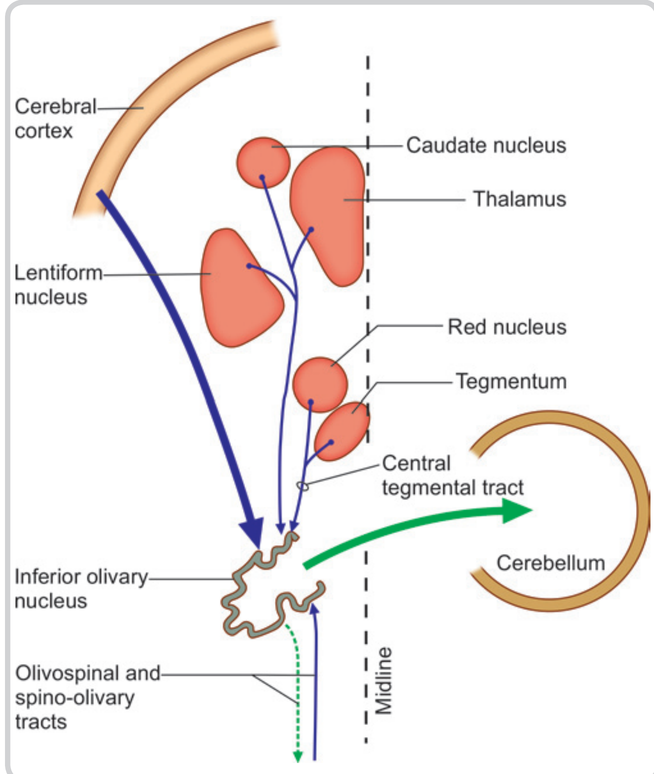

Figure 8.5: Scheme to show the connections of the inferior olivary nucleus

round the anterior and lateral aspect of the medulla as ***anterior external arcuate fibres*** to reach the inferior cerebellar peduncle of the opposite side. Other fibres pass dorsally through the substance of the medulla to reach the floor of the fourth ventricle. Here, they run under the ependyma to the inferior cerebellar peduncle of the opposite side as fibres of the ***striae medullares***. Fibres from the arcuate nuclei end in the flocculus of the cerebellum.

Students must distinguish between the striae medullaris described above and the striae medullaris thalami present in relation to the wall of the third ventricle.

Like the arcuate nuclei, the ***pontobulbar body*** is made up of neurons that represent displaced pontine nuclei. Fibres arising in this body form the ***circumolivary bundle***. These fibres join those from the arcuate nuclei to reach the inferior cerebellar peduncle of the opposite side. Some of them possibly pass through the striae medullaris.

Clinical Correlation

- ***Thrombosis of an artery*** supplying the medulla produces symptoms depending upon the structures involved. Two characteristic syndromes are the ***medial medullary syndrome*** produced by thrombosis in the anterior spinal artery, and the ***lateral medullary syndrome*** or ***Wallenberg syndrome*** produced by

Contd...

thrombosis of the posterior inferior cerebellar artery (Figures 8.6 and 8.7 and Table 8.1).

- ***Bulbar palsy*** is paralysis of the bulb, i.e. the medulla oblongata—involving the cranial nerve nuclei of medulla. It is characterized by lower motor neuron type of paralysis of IX, X, XI and XII cranial nerves resulting in dysphagia, dysphonia and dysarthria.

- ***Pseudobulbar palsy*** is a condition which develops as a part of ***motor neuron disease*** and is due to disruption of corticobulbar fibres which end in the cranial nerve nuclei of medulla oblongata (bulb). This produces upper motor neuron type of paralysis of affected cranial nerves and inappropriate laughter and crying.

Table 8.1 | Anatomical basis of clinical syndromes affecting medulla oblongata

Name of the syndrome	Structure affected	Clinical effect produced
Medial medullary syndrome (Dejerine's anterior bulbar syndrome) (Figure 8.6)	Corticospinal fibres (pyramids)	Contralateral hemiplegia
	Hypoglossal nucleus and nerve fibres	Ipsilateral (lower motor neuron type) paralysis of muscles of tongue (on protrusion, tongue deviates to the side of lesion)
	Medial lemniscus	Contralateral loss of sensation of fine touch, sense of movement and sense of position
Lateral medullary syndrome (Wallenberg syndrome or posterior inferior cerebellar artery syndrome (PICA) syndrome) (Figure 8.7)	Inferior cerebellar peduncle	Loss of equilibrium (ataxia) and giddiness
	Lateral spinothalamic tract	Loss of sensation of pain and temperature over the contralateral half of the body
	Spinal nucleus and tract of the trigeminal nerve	Loss of sensation of pain and temperature over the ipsilateral half of the head and face
	Nucleus ambiguus	Difficulty in swallowing (dysphagia) and in speech (dysarthria)
	Vestibular nuclei	Vomiting, nystagmus and vertigo
	Descending autonomic fibres	Ipsilateral Horner's syndrome characterized by ptosis, miosis, enophthalmos, anhydrosis and loss of ciliospinal reflex
Medullary tegmental paralysis (Babinski-Nageotte syndrome)	Lesion at pontomedullary junction involving all the above structures	Combination of medial and lateral medullary syndromes

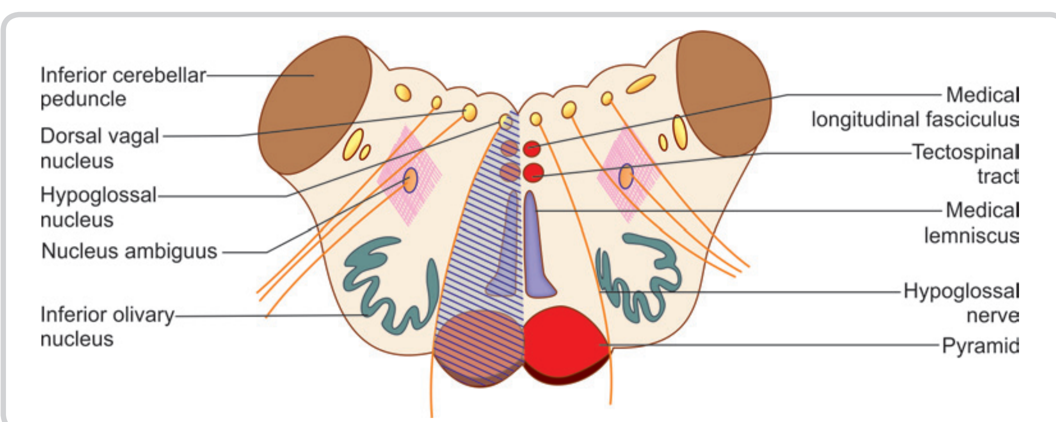

Figure 8.6: Occlusion of medullary branches of anterior spinal artery which causes medial medullary syndrome (shaded area)

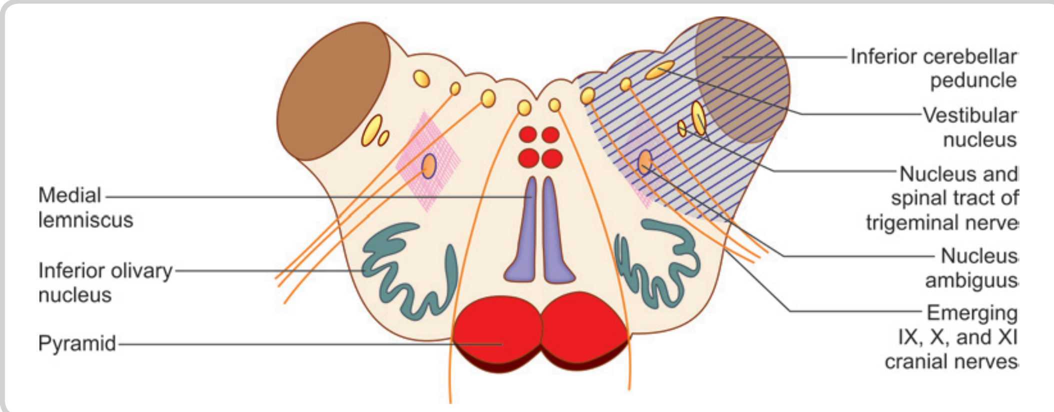

Figure 8.7: Occlusion of posterior inferior cerebellar artery which causes lateral medullary syndrome (shaded area)

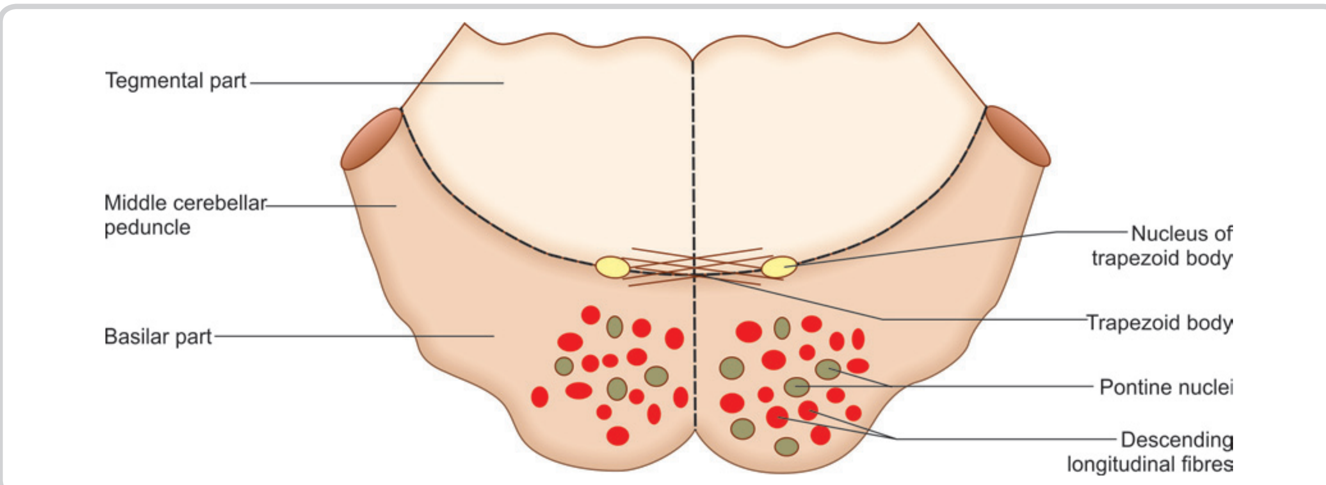

Figure 8.8: Diagramatic representation of lower part of the pons showing the basilar part of pons lying ventral to the trapezoid body and the tegmental part of the pons lying dorsal to it

PONS

The pons is divisible into a ***ventral part*** (basilar) and a ***dorsal part*** (tegmentum) (Figure 8.8).

Structure of the Basilar Part of Pons

The ventral (or basilar) part contains numerous transverse and vertical fibres. Amongst the fibres are the groups of cells that constitute the ***pontine nuclei*** (Figure 8.8).

The Pontine Nuclei

The pontine nuclei (or ***nuclei pontis***) are small masses of grey matter scattered between longitudinal and transversally arranged fibres. They are a relay station in the corticopontocerebellar pathway, i.e. between the cerebral cortex and contralateral cerebellar hemisphere.

They receive corticopontine fibres from the frontal, temporal, parietal, and occipital lobes of the cerebrum. Their efferents form the transverse fibres of the pons known as pontocerebellar fibres because they terminate at the cerebellum. Most of these fibres cross to the opposite side, but some may end ipsilaterally.

The pontine nuclei also receive fibres from various other sources, including the tectum (superior colliculus), the mammillary body, the lateral geniculate body, the nuclei gracilis and cuneatus, trigeminal nuclei, hypothalamus, cerebellar nuclei, and reticular formation.

It has been estimated that there are about 20 million neurons in pontine nuclei. Most of them are glutaminergic. About 5% are gamma-aminobutyric acid (GABA)-ergic and are inhibitory.

Descending Longitudinal Fibres

The descending longitudinal fibres (Figure 8.8) consist of:

- ***Corticospinal fibres*** as they traverse the pons and converge again to form pyramid in medulla.

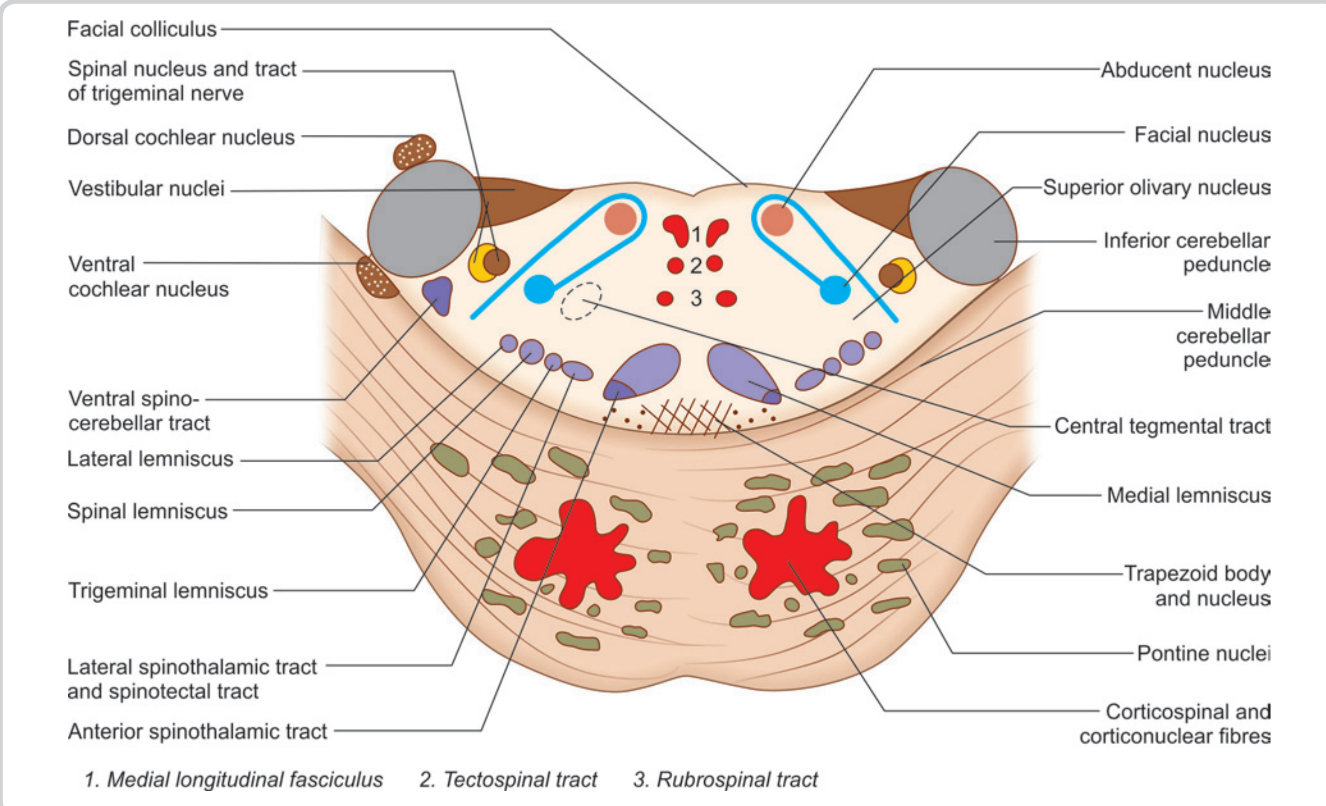

Figure 8.9: Transverse section through the lower part of the pons (at the level of facial colliculi)

- ***Corticonuclear fibres*** as they descend along with the corticospinal fibres to form pyramids in medulla. However, most of them terminate in the contralateral (and to some extent ipsilateral) motor nuclei of the cranial nerves.
- ***Corticopontine fibres*** as discussed, these fibres arise from frontal, temporal, parietal, and occipital cortices and terminate on pontine nuclei of same side.

Transverse Pontine Fibres

Transverse fibres arise in the pontine nuclei and cross to the opposite side to form the middle cerebellar peduncle. These are ***pontocerebellar fibres***.

Trapezoid body which separates the basilar and the tegmental parts of the pons consists of decussating fibres of ventral cochlear nuclei and thus is a part of auditory pathway. The fibres which cross at the trapezoid body ascend up as lateral lemniscus.

Structure of the Tegmental Part of Pons

The dorsal part (or tegmentum) of the pons may be regarded as an upward continuation of the part of the medulla behind the pyramids. Superiorly, it is continuous with the tegmentum of the midbrain. It is bounded posteriorly by the fourth ventricle. Laterally, it is related to the inferior cerebellar peduncles in its lower part

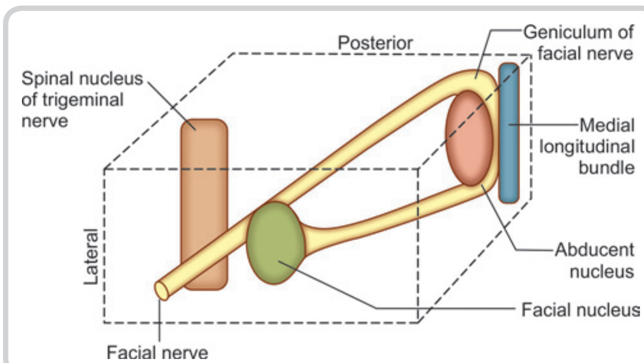

Figure 8.10: Scheme to show the course of the fibres of the facial nerve through the pons and formation of the facial colliculus

(Figure 8.9) and to the ***superior cerebellar peduncles*** in its upper part (Figure 8.11). The spinal nucleus and tract of the trigeminal nerve lie just medial to these peduncles.

Internal Structure of Pons

The region adjoining the ventral part (of the pons) is occupied by important ascending tracts. The medial lemniscus occupies a transversely elongated oval area next to the midline. Lateral to this are the trigeminal and the spinal lemniscus (lateral spinothalamic tract). The

fibres of the spinotectal tract run along with the spinal lemniscus, while those of the ventral spinothalamic tract lie within the medial lemniscus. Still more laterally, there is lateral lemniscus.

Ventral to these lemnisci, there are conspicuous transversely running fibres that form the ***trapezoid body***.

The ventral spinocerebellar tract lies ventromedial to the inferior cerebellar peduncle in the lower part of the pons (Figure 8.9). In the upper part of the pons, it is seen within the superior cerebellar peduncle (Figure 8.11).

Descending tracts passing through the dorsal part of the pons are the tectospinal tract and the rubrospinal tract. The medial longitudinal fasciculus lies dorsally near the midline.

However, the structure of the tegmentum is different in the upper and lower part of pons. Hence, it is customary to study the internal structure of pons at two different levels—lower part, transverse section passing through the facial colliculi and upper part, transverse section passing through trigeminal nuclei (Figures 8.1 D and E).

SECTION THROUGH LOWER PART OF PONS (AT THE LEVEL OF FACIAL COLLICULI)

The transverse section through the lower part of pons corresponds to the level of facial colliculi (Figure 8.1D).

This section (Figure 8.9) shows two cranial nerve nuclei that are closely related to the floor of the fourth ventricle. These are the ***abducent nucleus***, lying medially and the ***vestibular nuclei*** that lie laterally.

At a deeper level in the lateral part of the reticular formation, two additional nuclei are seen. These are the ***spinal nucleus of the trigeminal nerve*** (along with its tract), lying laterally and the ***facial nucleus,*** lying medially. The dorsal and ventral cochlear nuclei lie dorsal and ventral, respectively to the inferior cerebellar peduncle.

The fibres arising from the facial nucleus follow an unusual course (Figure 8.10). They first run dorsally and medially to reach the lower pole of the abducent nucleus. They then ascend on the medial side of that nucleus. Here, the fibres are closely related to the medial longitudinal fasciculus. Finally, the fibres of the facial nerve turn forwards and laterally passing above the upper pole of the abducent nucleus. As they pass ventrally, the fibres lie between the facial nucleus medially and the spinal nucleus of the trigeminal nerve laterally. The abducent nucleus and the facial nerve fibres looping around it, **internal genu or geniculum of facial nerve** together form a surface elevation, the ***facial colliculus*** (Figure 8.10)***,*** in the floor of the fourth ventricle.

The vestibular nuclei occupy the vestibular area in the lateral part of the floor of the fourth ventricle. These nuclei are to be seen in the lower part of the pons and in the upper part of the medulla (Figures 8.9 and 8.4).

Other masses of grey matter to be seen in the lower part of the pons are the ***superior olivary complex*** (made up of several nuclei), which lies dorsomedial to the lateral lemniscus and the nuclei of the trapezoid body, which consists of scattered cells lying within this body.

SECTION THROUGH UPPER PART OF PONS (AT THE LEVEL OF TRIGEMINAL NERVE)

The transverse section through the upper part of pons passes through the motor and principal sensory nuclei of the trigeminal nerve (Figure 8.1E).

At this level (Figure 8.11), the dorsal part is bounded laterally by the superior cerebellar peduncles. Medial to each peduncle, there is main sensory nucleus of the trigeminal nerve and further medially, there is motor nucleus of the same nerve. The superior olivary nucleus extends to this level but is less prominent, while the lateral lemniscus forms a more conspicuous bundle. Some fibres of the trapezoid body can be seen ventral to the medial lemniscus.

Table 8.2 | Alternating Hemiplegias

Name of the syndrome	Structure involved	Clinical effects produced
Millard-Gubler syndrome (Figure 8.12)	Corticospinal tracts	Contralateral hemiplegia
	Abducent nerve rootlets	Ipsilateral lower motor neuron type paralysis of abducent nerve resulting in internal squint
	Facial nerve and its nucleus	Ipsilateral lower motor neuron type paralysis of facial nerve
Raymond-Foville syndrome (Figure 8.13)	Corticospinal tracts	Contralateral hemiplegia
	Abducent nerve	Conjugate gaze palsy
	Facial nerve and its nucleus	Ipsilateral lower motor neuron type paralysis of facial nerve

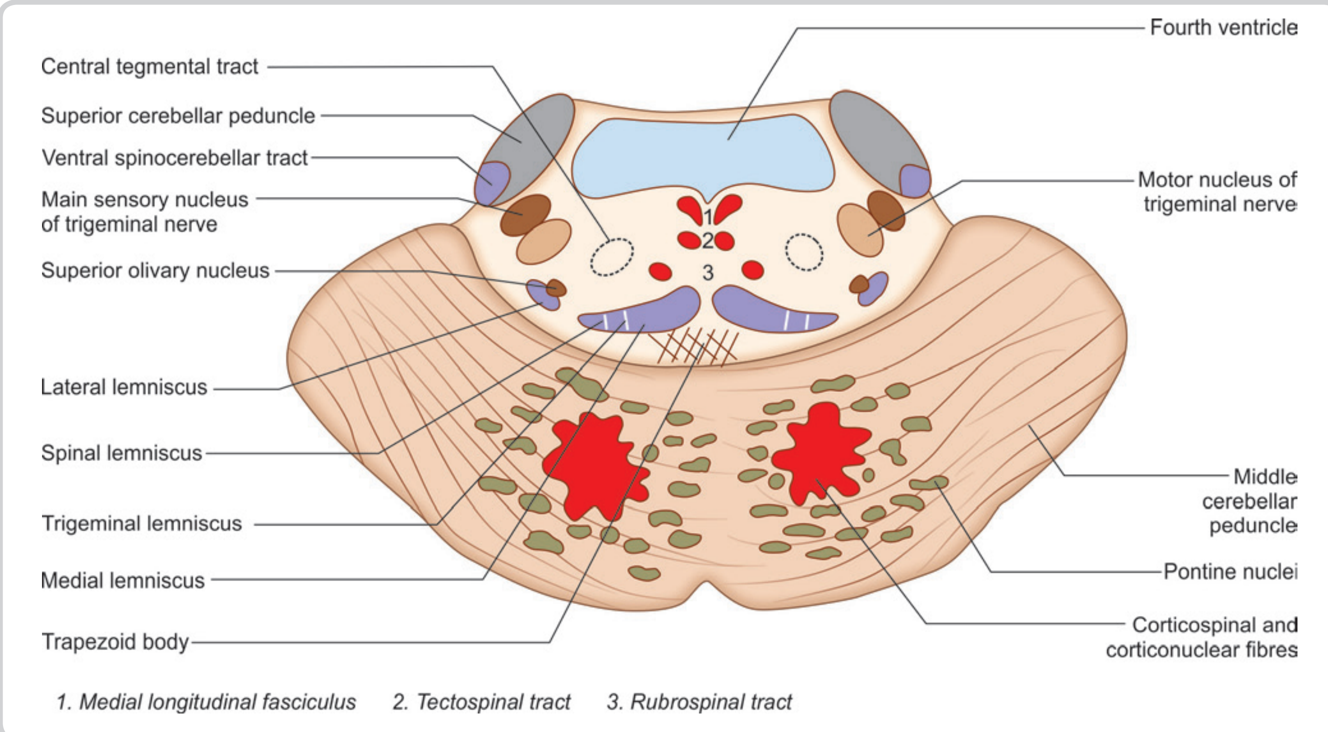

Figure 8.11: Transverse section through the upper part of the pons

> **Clinical Correlation**
>
> **Pontine Hemorrhage**
>
> Haemorrhage into the pons leads to coma (and is often fatal). The reticular formation, autonomic nervous system constituting fibres from hypothalamus are affected. Apart from coma, the condition is marked by pin point pupils and hyperpyrexia. Bilateral facial paralysis and paralysis of all four limbs can occur if the haemorrhage is extensive. (**PPP-P**inpoint pupils, **P**yrexia and **P**aralysis).
>
> **Locked-in Syndrome**
>
> It is due to infarction of the basal part of pons involving the corticospinal tracts and the corticobulbar fibres of both sides. The patient will present with complete paralysis due to involvement of corticospinal tracts and aphonia due to involvement of corticobulbar fibres. Since the ascending fibres are unaffected, all general and special sensory inputs are normal. The only way the patient can communicate is by blinking and by vertical gaze.
>
> **Alternating Hemiplegias**
>
> These occur when the descending corticospinal fibres along with the cranial nerve nuclei and nerve fibres get affected due to vascular occlusion. Such a lesion, seen usually in the brainstem vascular occlusions, result in contralateral hemiplegia and ipsilateral lower motor neuron paralysis of the cranial nerve. This is called as ***alternating hemiplegia*** or ***crossed hemiplegia*** (Table 8.2).

MIDBRAIN

For convenience of description, the midbrain may be divided as follows (Figure 8.14 and 8.15).

- The part lying dorsal to a transverse line drawn through the cerebral aqueduct is called the ***tectum***. It consists of the ***superior and inferior colliculi*** of the two sides.
- The part lying ventral to the transverse line is made up of right and left halves called the ***cerebral peduncles***. Each peduncle consists of three parts. From anterior to posterior, these are the ***crus cerebri*** the ***substantia nigra,*** and the ***tegmentum***.

Crus Cerebri

The crus cerebri consists of a large mass of vertically running fibres, which descend from the cerebral cortex. The fibres in the crus cerebri consist of the following:

- Corticopontine fibres
- Corticospinal fibres
- Corticonuclear fibres

Its medial one-sixth is occupied by corticopontine fibres descending from the frontal lobe and the lateral one-sixth is occupied by similar fibres from the temporal, occipital, and parietal lobes. The intermediate two-thirds of the crus cerebri are occupied by corticospinal and corticonuclear fibres (Figure 8.15). The fibres for the leg are most lateral and those for the head are most medial.

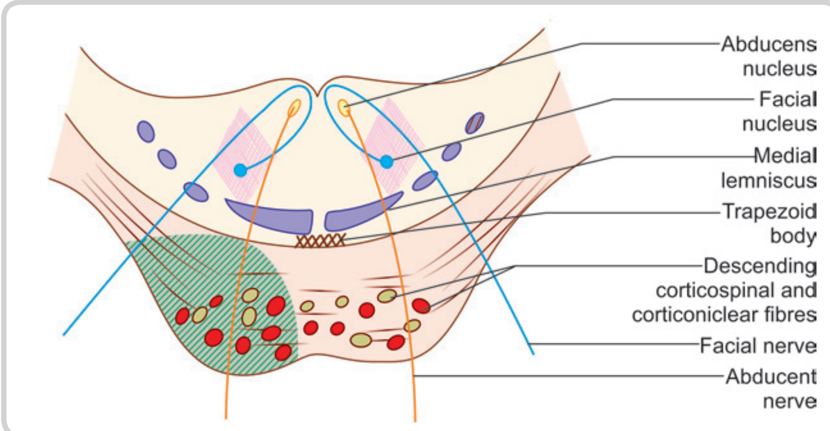

Figure 8.12: Schematic diagram to show Millard-Gubler syndrome (shaded area)

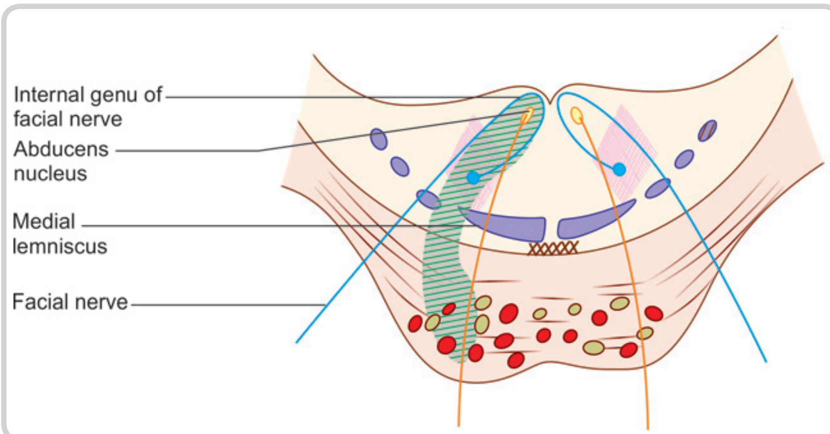

Figure 8.13: Schematic diagram to show Raymond-Foville syndrome (shaded area)

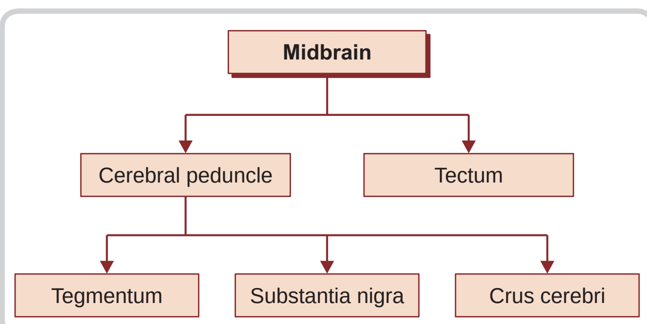

Figure 8.14: Flowchart showing parts of midbrain

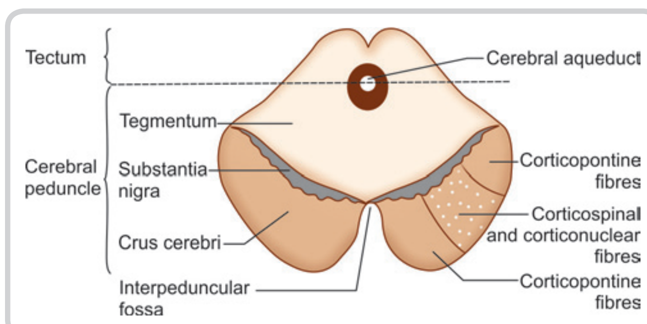

Figure 8.15: Transverse section of the midbrain showing its main subdivision

Substantia Nigra

The ***substantia nigra*** lies immediately behind and medial to the crus cerebri (Figure 8.15). It appears dark in unstained sections, as neurons within it contain a pigment (***neuromelanin***).

The substantia nigra is divisible into a dorsal part, the ***pars compacta*** and a ventral part, the ***pars reticularis***. The pars compacta contains dopaminergic and cholinergic neurons. Most of the neurons in the pars reticularis are GABAergic. Superiorly, the pars reticularis becomes continuous with the globus pallidus. The substantia nigra is closely connected, functionally, with the corpus striatum.

Connections of Substantia Nigra

The main connections (both afferent and efferent) of substantia nigra are with the striatum (i.e., caudate nucleus and putamen). Dopamine produced by neurons

in the substantia nigra (pars compacta) passes along their axons to the striatum (***mesostriatal dopamine system***).

> **Clinical Correlation**
>
> Dopamine is much reduced in patients with a disease called ***Parkinsonism***, in which there is degeneration of the striatum.

Along with other groups of dopaminergic neurons present in the ventral part of the tegmentum, the substantia nigra is believed to be a neural centre for "adaptive behaviour". Efferents of this system are widely distributed.

The midbrain is traversed by the cerebral aqueduct, which is surrounded by central grey matter. Ventrally, the central grey matter is related to cranial nerve nuclei (oculomotor and trochlear) (Figures 8.16). The region between the substantia nigra and the central grey matter is occupied by the reticular formation.

Tegmentum

The tegmentum is the region of midbrain that lies between substantia nigra and tectum (Figure 8.15).

The tegmentum of the two sides is continuous across the midline. It contains important masses of grey matter as well as fibre bundles. The largest of the nuclei is the ***red nucleus*** (Figure 8.19) present in the upper half of the midbrain. The tegmentum also contains the ***reticular formation,*** which is continuous below with that of the pons and medulla.

The internal structure of tegmentum and tectum varies at different levels of midbrain; hence, the internal structure of midbrain is studied by transverse sections at two different levels—lower part, transverse section passing through the inferior colliculi and upper part, transverse section passing through superior colliculi (Figure 8.1F and G).

SECTION THROUGH MIDBRAIN AT THE LEVEL OF INFERIOR COLLICULI (FIGURE 8.1F)

A section through the midbrain at the level of the inferior colliculus shows the following features (Figure 8.16).

- The ***trochlear nucleus*** lies in the ventral part of the central grey matter. Fibres arising in this nucleus follow an unusual course. They run dorsally and decussate (in the superior medullary velum) before emerging on the dorsal aspect of the brainstem.
- The ***mesencephalic nucleus of the trigeminal nerve*** lies in the lateral part of the central grey matter.
- A compact bundle of fibres lies in the tegmentum dorsomedial to the substantia nigra. It consists of the medial lemniscus (lies just behind the substantial nigra lateral to the red nucleus), the trigeminal lemniscus, and the spinal lemniscus in that order from medial to lateral side.

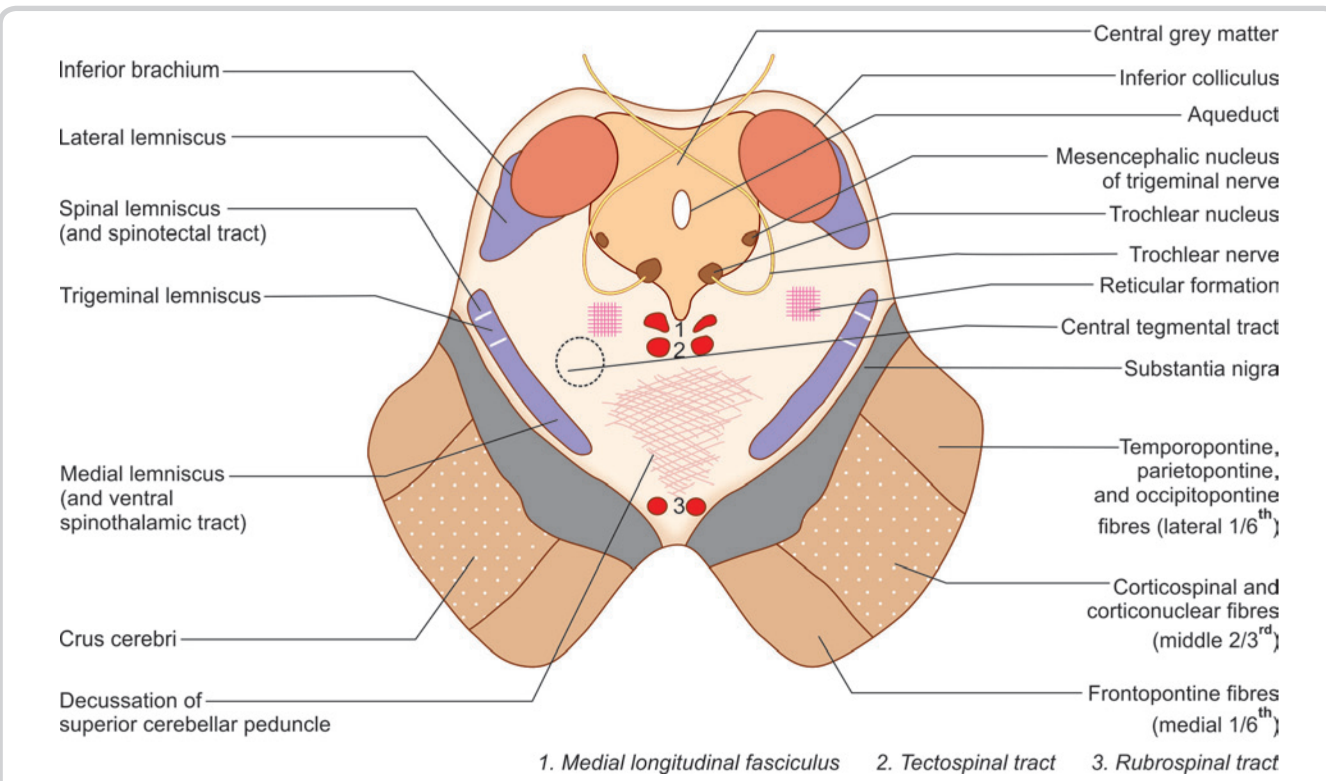

Figure 8.16: Transverse section through the lower part of the midbrain at the level of inferior colliculus.

- The medial lemniscus includes fibres of the ventral spinothalamic tract, while the spinal lemniscus (made up mainly of the lateral spinothalamic tract) includes fibres of the spinotectal tract. More dorsally, the lateral lemniscus forms a bundle ventrolateral to the inferior colliculus (in which most of its fibres end).
- Important fibre bundles are also located near the midline of the tegmentum. The medial longitudinal fasciculus lies ventral to the trochlear nucleus, and ventral to the fasciculus, there is tectospinal tract.
- The region ventral to the tectospinal tracts is occupied by decussating fibres of the superior cerebellar peduncle. These fibres have their origin in the dentate nucleus of the cerebellum. They cross the midline in the lower part of the tegmentum. Some of these fibres end in the red nucleus while others ascend to the thalamus.
- The part of the tegmentum ventral to the decussation of the superior cerebellar peduncle is occupied by the rubrospinal tracts.

The ***inferior colliculus*** is a large mass of grey matter lying in the tectum. It forms a cell station in the auditory pathway and is probably concerned with reflexes involving the auditory stimuli.

Connections of Inferior Colliculus

The inferior colliculus is an important relay centre in the auditory pathway.

Afferent Fibres

It receives fibres of the lateral lemniscus arising in the superior olivary complex (Figures 8.17 and 8.18). Each colliculus receives auditory impulses from both the ears.

Inferior Colliculus

Afferents
- Lateral lemniscus from superior olivary nucleus

Efferents
- Medial geniculate body
- Inferior Colliculus (opposite side)
- Superior Colliculus (same side)

Figure 8.17: Flowchart depicting connections of inferior colliculus

Efferent Fibres

Auditory impulses from inferior colliculus are relayed to the medial geniculate body (the fibres passing through the inferior brachium) and from there, to the auditory (acoustic) area of the cerebral cortex. Some efferents from the inferior colliculus terminate in the contralateral (opposite) inferior colliculus. These connections are responsible for the bilateral cortical projection of auditory information from each ear (Figures 8.17 and 8.18).

Efferents from the inferior colliculus also project to the superior colliculus of the same side. The superior colliculus, in turn, sends these auditory signals to the brainstem and to the cervical part of the spinal cord via tectotegmental and tectospinal tracts respectively.

Traditionally, the inferior colliculi have been regarded as reflex centres for responses to auditory stimuli. The colliculi are important in differentiating sounds received by the two ears and, thus, in locating the source of sound.

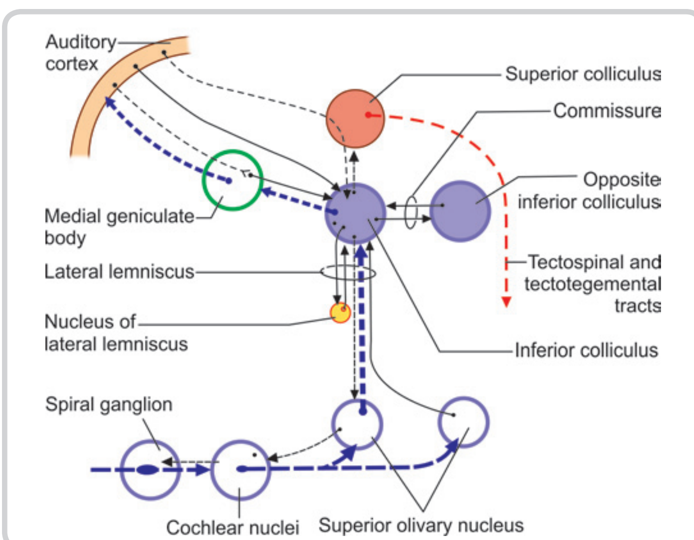

Figure 8.18: Scheme to show the connections of the inferior colliculus

Each inferior colliculus has a main nucleus (placed centrally). This nucleus is divisible into dorsomedial and ventrolateral zones. More superficially, in the colliculus, there is a dorsal cortex, which is divided into four laminae. The neurons of the inferior colliculus are arranged in groups responding to different frequencies of sound. Those in the dorsal part of the central nucleus respond to low frequencies, while ventrally placed cells respond to higher frequencies. Recent studies suggest that a frequency distribution map exists at all levels of the auditory pathway.

Clinical Correlation

- Lesions of the inferior colliculus produce defects in appreciation of tones, localization of sound, and reflex movements in response to sound.

SECTION THROUGH MIDBRAIN AT THE LEVEL OF SUPERIOR COLLICULI (FIGURE 8.1G)

A section through the upper part of the midbrain (Figure 8.18) shows two large oval masses of grey matter not seen at lower levels. These are the ***red nucleui*** in the tegmentum.

- The ***oculomotor nucleus*** lies in relation to the ventral part of the central grey matter. The nuclei of the two sides lie close together forming a single complex. The ***Edinger Westphal nucleus*** (which supplies the sphincter pupillae and ciliaris muscle) forms part of the oculomotor complex. The oculomotor complex is related ventrally to the medial longitudinal fasciculus (Figure 8.19).
- Closely related to the cranial part of the superior colliculus, there is a small collection of neurons that constitute the ***pretectal nucleus***. This nucleus is concerned with the pathway for the pupillary light reflex.
- The pretectal nucleus extends cranially to the junction of the midbrain with the diencephalon. It receives retinal fibres through the optic tract. It also receives some fibres from the superior colliculus and from the visual cortex. The main efferents of the nucleus reach the oculomotor nuclei (of both sides). Some efferents reach the superior colliculus and the pulvinar.
- The bundle of ascending fibres consisting of the medial lemniscus, the trigeminal lemniscus and the spinal lemniscus lies more dorsally than at lower levels (because of the presence of the red nucleus). The lateral lemniscus is not seen at this level as its fibres end in the inferior colliculus. However, the ***inferior brachium*** that conveys auditory fibres to the medial geniculate body can be seen near the surface of the tegmentum. The region of the tegmentum near the midline shows two groups of decussating fibres. The ***dorsal tegmental decussation*** consists of fibres that have their origin in the superior colliculus and cross to the opposite side to descend as the tectospinal tract. The ***ventral tegmental decussation*** consists of fibres that originate in the red nucleus and decussate to form the rubrospinal tracts.

The **red nucleus** lies in the anterior part of the tegmentum dorsomedial to the substantia nigra. It is

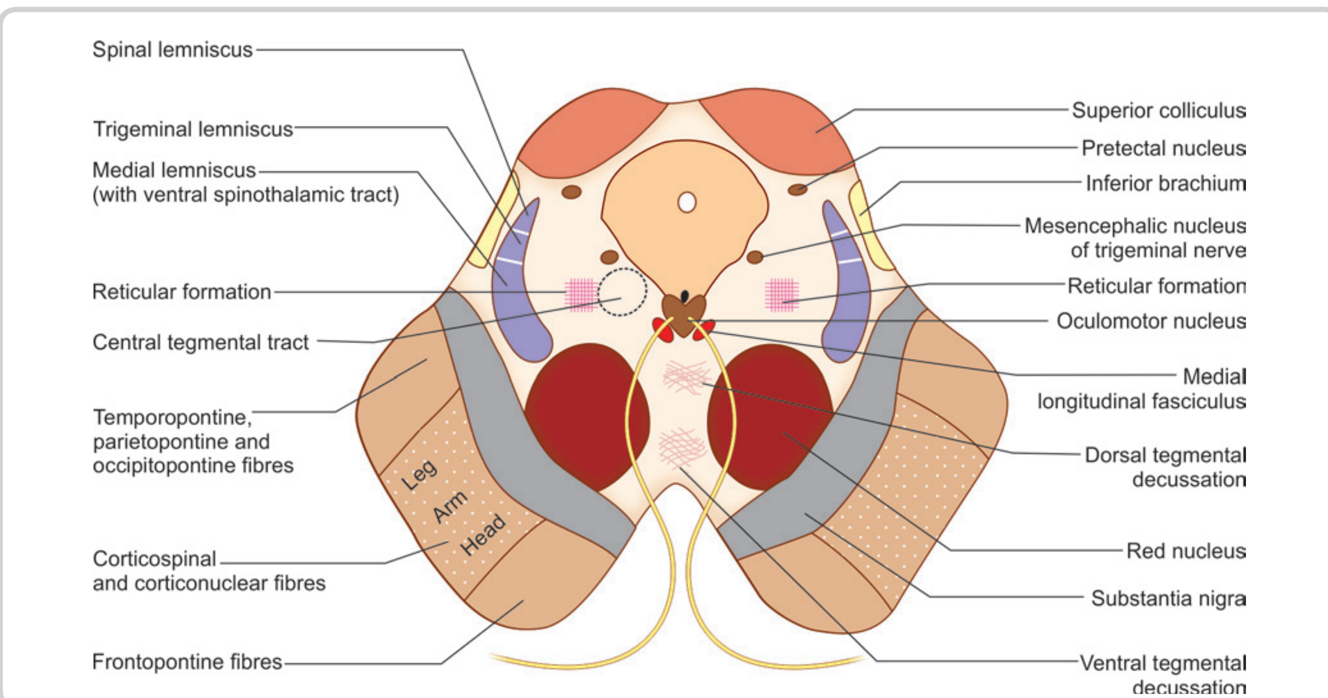

Figure 8.19: Transverse section through the upper part of the midbrain at the level of superior colliculi

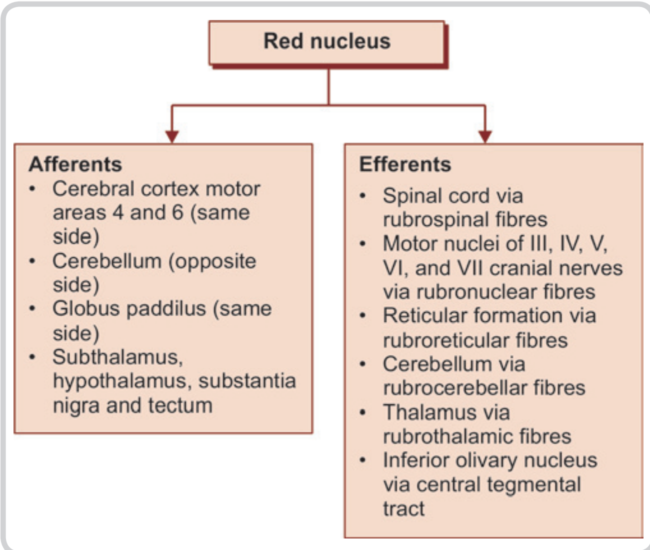

Figure 8.20: Flowchart showing the connections of the red nucleus

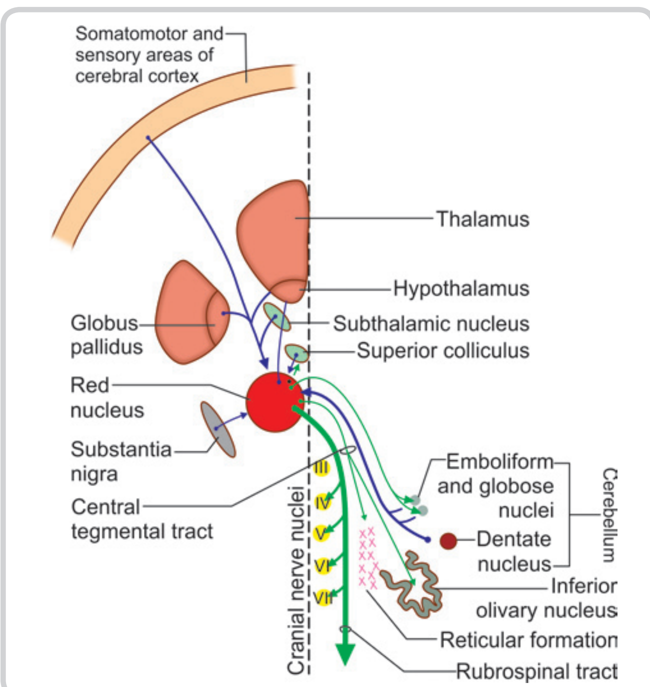

Figure 8.21: Scheme to show the connections of the red nucleus

so called, because of a reddish colour in fresh material. The colour is produced by the presence of an iron oxide in its neurons. The red nucleus consists of a cranial parvicellular part and a caudal magnocellular part. The magnocellular part is prominent in lower species, but in man, it is much reduced, and is distinctly smaller than the parvicellular part. It is an important motor nucleus of the extrapyramidal system. The connections of the red nucleus are considered below and are shown in Figures 8.20 and 8.21.

Connections of Red Nucleus

Afferent Fibres

The red nucleus receives its main afferents from:

- Cerebral cortex (from motor area—area 4 and 6 of frontal cortex of same side)
- Cerebellum (dentate, emboliform, and globose nuclei of opposite side)
- Globus pallidus of the same side
- Subthalamic nucleus, hypothalamus, substantia nigra and tectum

Efferent Fibres

The efferent fibres from the red nucleus cross in the ventral tegmental decussation and then go to

- Spinal cord (rubrospinal tract)
- Cranial nerve motor nuclei III, IV, V, VI, and VII (rubronuclear)
- Inferior olivary nucleus (central tegmental fasciculus)
- Reticular formation (rubroreticular)
- Substantia nigra, cerebral cortex and thalamus

The **superior colliculus** is a centre concerned with visual reflexes. Its connections are shown in Figures 8.22 and 8.23 and discussed below.

Connections of Superior Colliculus

The superior colliculus has a complex laminar structure, being made up of seven alternating layers of white and grey matter.

Afferent Fibres (Figures 8.22 and 8.23)

The superior colliculus receives afferent fibres from:

- Retina (mostly contralateral) through the lateral geniculate body and superior brachium
- Spinal cord (pain and tactile fibres) through spinotectal tract
- Frontal and occipital visual cortex (conjugate eye movements)
- Inferior colliculus

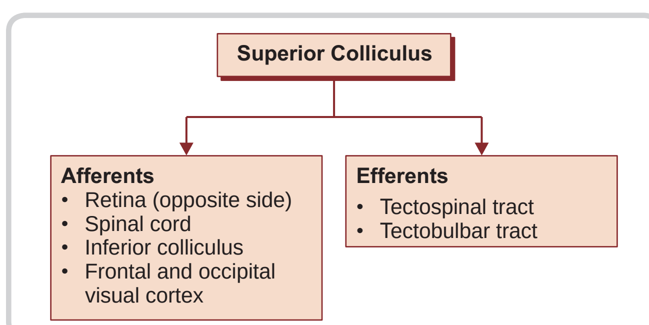

Figure 8.22: Flowchart showing connections of the superior colliculus.

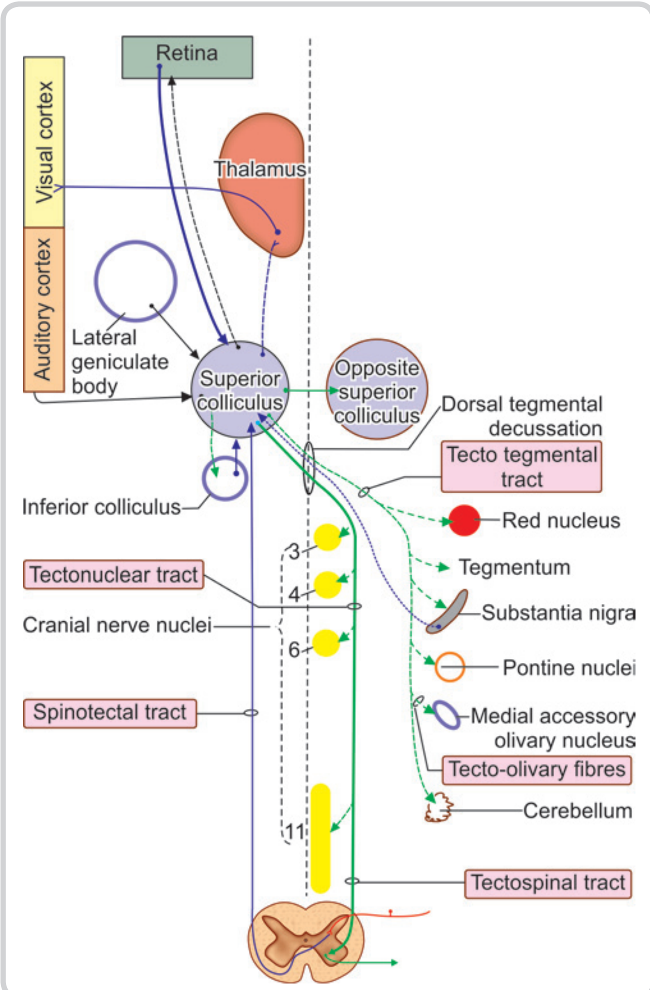

Figure 8.23: Scheme to show the connections of the superior colliculus—the connections to the visual cortex through the thalamus provide an extra-geniculate retino-cortical pathway

Efferent Fibres

The major efferents are:

- Tectospinal tract and tectobulbar tract fibres to the nuclei of cranial nerves, responsible for moving the eyes and head.
- Some efferents also reach the retina. The superior colliculi have, therefore, been regarded as a centre for reflex movements of the head and eyes in response to visual stimuli.
- The colliculi also send efferents to various centres in the brainstem (red nucleus, substantia nigra and reticular formation)
- Cerebellum through the pontine nuclei
- Reticular nuclei in the midbrain, pons, and medulla

From these connections, it appears likely that the superior colliculi are concerned with complex interactions between visual inputs and various activities of the body.

Some fibres descend to the superior colliculus from the auditory cortex and may be involved in integration of visual and auditory behaviour.

Some Fibre Bundles Seen in the Brainstem

In addition to the various ascending and descending tracts described here, there are a number of fibre bundles seen in the brainstem. These include:

- Medial longitudinal fasciculus (or bundle)
- Central tegmental tract
- Dorsal longitudinal fasciculus

Parts of the medial forebrain bundle and of the mammillary peduncle are also seen.

Midbrain may get affected by occlusions of blood vessels supplying it. Various clinical syndromes produced in lesions of midbrain are listed in Table 8.3.

Medial Longitudinal Fasciculus (MLF)

The medial longitudinal fasciculus consists of fibres arising mainly from right and left medial vestibular nuclei in the medulla (however, some fibres also from nucleus of lateral leminiscus and interstitial nucleus of cajal) (Figure 9.10).

The fasciculus is closely related and connected to the nuclei of the third, fourth, sixth, and twelfth cranial nerves

Clinical Correlation

Table 8.3 | Anatomical basis of clinical syndromes affecting midbrain

Name of the syndrome	Structures affected	Clinical effects produced
Weber syndrome (Figure 8.24)	Corticospinal tract	Contralateral hemiplegia
	Oculomotor nerve	Ipsilateral lower motor neuron type oculomotor nerve palsy with lateral squint
Benedikt syndrome (Figure 8.25)	Oculomotor nerve rootlets	Ipsilateral lower motor neuron type oculomotor nerve palsy with lateral squint
	Red nucleus	Contralateral coarse tremors
	Medial lemniscus	Contralateral hemianaesthesia
Parinaud syndrome	Nucleus of posterior commissure	Upward gaze palsy

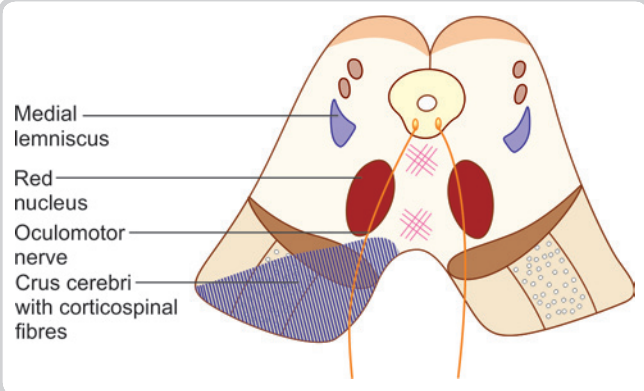

Figure 8.24: Schematic diagram showing Weber syndrome (shaded area)

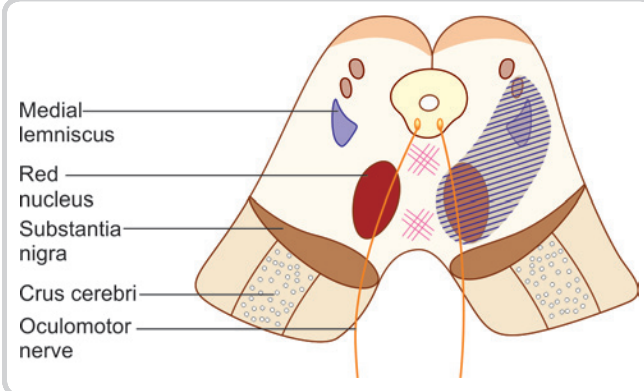

Figure 8.25: Schematic diagram showing Benedikt syndrome (shaded area)

(all of the somatic efferent column and lying next to the midline). It is also related to the fibres of the seventh nerve (as they wind round the abducent nucleus) and some fibres arising from the cochlear nuclei.

Fibres of medial longitudinal fasciculus of each side cross the midline at the posterior commissure. Further details are given in chapter 9.

RETICULAR FORMATION OF THE BRAINSTEM

The term reticular formation was originally used to designate areas of the central nervous system which were not occupied by well-defined nuclei or fibre bundles, but consisted of a network of fibres within which scattered neurons were situated. Such areas are to be found at all levels in the nervous system. In the spinal cord there is an intermingling of grey and white matter on the lateral side of the neck of the dorsal grey column. This area is sometimes referred to as the reticular formation of the spinal cord. The reticular formation is, however, best defined in the brainstem where it is now recognized as an area of considerable importance. Some centres in the cerebrum and cerebellum are regarded by some authorities to be closely related, functionally, to this region.

The reticular formation extends throughout the length of the brainstem. In the medulla it occupies the region dorsal to the inferior olivary nucleus. In the pons it lies in the dorsal part, while in the midbrain it lies in the tegmentum.

The neurons to be seen in the reticular formation vary considerably in the size of their cell bodies, the length and ramifications of their axons, and the behaviour of their dendrites. Many neurons have extensive dendritic trees and their ramifications may cover a wide extent both vertically and transversely. The connections of individual neurons are difficult to determine as many of the pathways concerned are polysynaptic.

A number of reticular nuclei have been described. The limits of such nuclei are ill-defined, and their functional significance is often obscure. The following scheme includes the better known nuclei of the reticular formation.

Nuclei of the Reticular Formation in the Brainstem

These can be divided into three longitudinal columns (in each half of the brainstem).

- The ***median column*** lies next to the midline. The nuclei in it are called the ***nuclei of the raphe,*** or ***paramedian nuclei.***
- The ***medial column*** (or ***magnocellular*** column) consists of nuclei having neurons of large or medium size.
- The nuclei of the ***lateral column*** are made up of small neurons. Because of this the lateral column is also referred to as the ***parvocellular column***. The nuclei to be seen in each of these columns are shown in Figure 8.26 and Table 8.4.

Chemoarchitectonics of reticular formation

With the development of immunofluorescence techniques a number of neuromediators have been demonstrated in the reticular formation. These include acetylcholine, noradrenaline, adrenaline, dopamine (confined to the midbrain), and serotonin. New maps of the reticular formation, based on the distribution of such neuromediators, are now being drawn up (as for other regions of the nervous system). Such studies have created a new interesting science of ***chemoarchitectonics***. It appears logical to assume that grouping of areas in this way may be of greater functional relevance than the division into ill-defined nuclei.

Many neurons in the raphe nuclei are serotoninergic and constitute part of a system that ramifies into the entire central nervous system.

Table 8.4 | Nuclei of the reticular formation in the brainstem. Also see Figure 8.28

	Median Column (Nuclei of Raphe)	Medial Column (Magnocellular)	Lateral Column (Parvocellular)
MIDBRAIN	Nucleus raphes dorsalis	Circumaqueductal grey Deep tegmental nucleus Dorsal tegmental nucleus Nucleus subcuneiformis Nucleus cuneiformis	Nucleus pedunculopontis Lateral parabrachial nucleus Medial parabrachial nucleus
PONS	Nucleus raphes centralis superior Nucleus raphes pontis Nucleus raphes magnus	Nucleus coeruleus Nucleus reticularis pontis oralis Nucleus reticularis tegmenti pontis Nucleus reticularis pontis caudalis Gigantocellular nucleus (pontine part)	Central nucleus of pons
MEDULLA	Nucleus raphes obscurus Nucleus raphes pallidus	Gigantocellular nucleus (medullary part)	Central nucleus of medulla Lateral reticular nucleus Ventral reticular nucleus

Connections of Reticular Formation

The reticular formation has numerous connections. Directly, or indirectly, it is connected to almost all parts of the nervous system. The better established afferents are shown in Figure 8.27; and the efferents in Figure 8.28.

The pathways involved are both ascending and descending; crossed and uncrossed; somatic and visceral. In the description that follows, the major pathways involving the reticular formation are taken up one by one. It must be emphasised, however, that the reticular formation is not to be regarded merely as a relay station on these pathways. It has an important regulatory role, both facilitatory and inhibitory.

Cortico-reticulo-spinal Pathways

The reticular formation receives impulses from the motor and other areas of the cerebral cortex and relays them to the spinal cord through the medial and lat eral reticulospinal tracts. The corticoreticular fibres descend along with corticospinal fibres. They terminate mainly in relation to the oral and caudal reticular nuclei of the pons, and the gigantocellular nucleus of the medulla. Fibres arising in the oral and caudal nuclei of the pons form the pontine (or medial) reticulospinal tract, while fibres arising in the gigantocellular nucleus form the medullary (or lateral) reticulospinal tract. Apart from these relatively better defined tracts reticulospinal fibres are widely scattered in the anterior and lateral funiculi of the spinal cord; and some descend through the intersegmental tracts. Apart from the nuclei mentioned above reticulospinal fibres may arise from other nuclei including the central nucleus of the medulla.

The reticular formation also establishes connections with motor cranial nerve nuclei.

Cerebelloreticular Connections

The following nuclei of the reticular formation have reciprocal connections with the cerebellum (Figure 8.29):

- Lateral reticular nucleus
- Paramedian reticular nucleus. It is located in the medulla within the medial longitudinal fasciculus.
- Pontine tegmental reticular nucleus

Through these connections the reticular formation connects the cerebral cortex, and the spinal cord, to the cerebellar cortex.

Ascending Reticular Activating System (ARAS)

It has been seen that many ascending tracts passing through the brainstem are intimately related to the reticular formation. Many of the fibres in these tracts give off collaterals to it. These come from the spinothalamic tracts, from secondary trigeminal pathways and from auditory pathways. These collaterals terminate predominantly in the lateral part of the reticular formation. Fibres arising here project to the intralaminar and reticular nuclei of the thalamus. These nuclei in turn project to widespread areas of the cerebral cortex. These pathways form part of the ***ascending reticular activating system*** (ARAS) which is believed to be responsible for maintaining a state of alertness.

Serotoninergic Raphe System

They are also referred to as the paramedian reticular nuclei. Special interest in the raphe nuclei has ensued after the demonstration that they are the central part of an

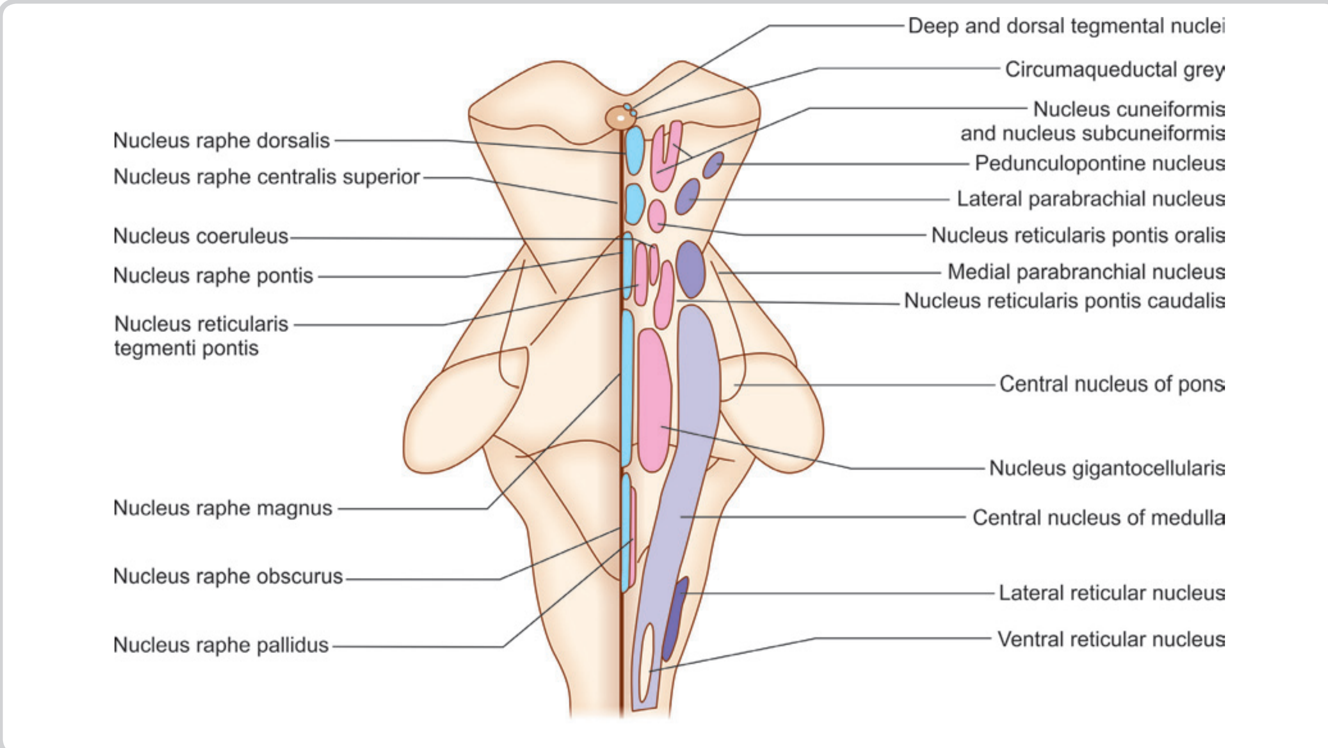

Figure 8.26: Scheme to show some nuclei in the reticular formation of the brainstem projected on to its posterior surface

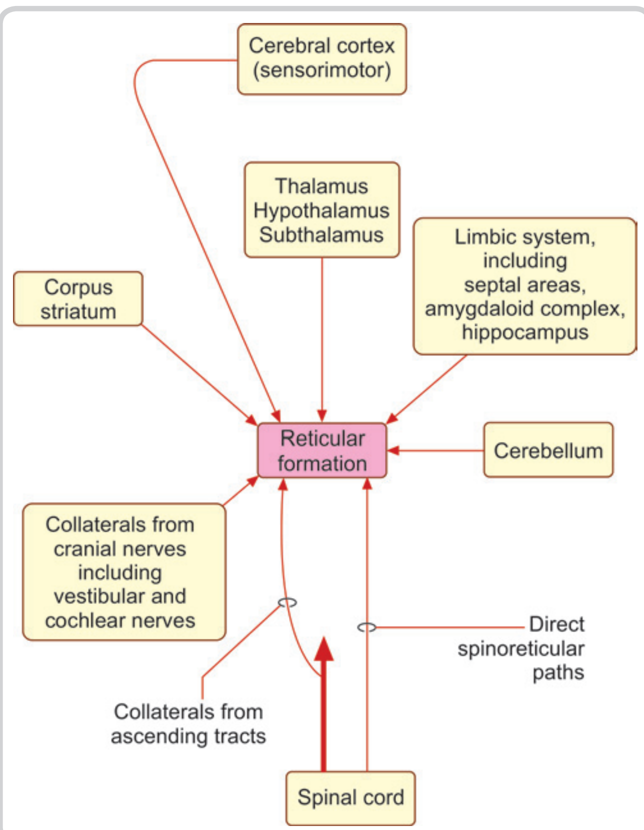

Figure 8.27: Scheme to show the major afferents of the reticular formation

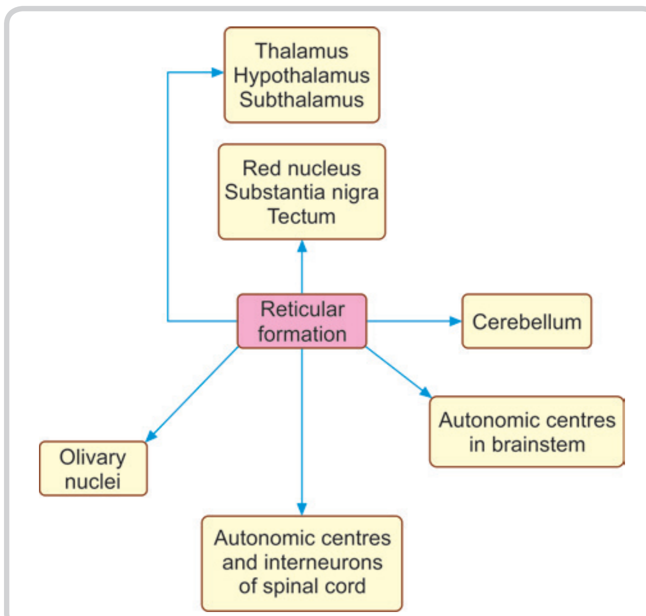

Figure 8.28: Scheme to show the major efferents of the reticular formation

extensive serotoninergic system that permeates the entire nervous system as summarized below (Figure 8.30).

- Serotoninergic fibres descending from the raphe nuclei (mainly of the medulla) reach all levels of the spinal cord. Dorsal (or lateral) and ventral pathways are

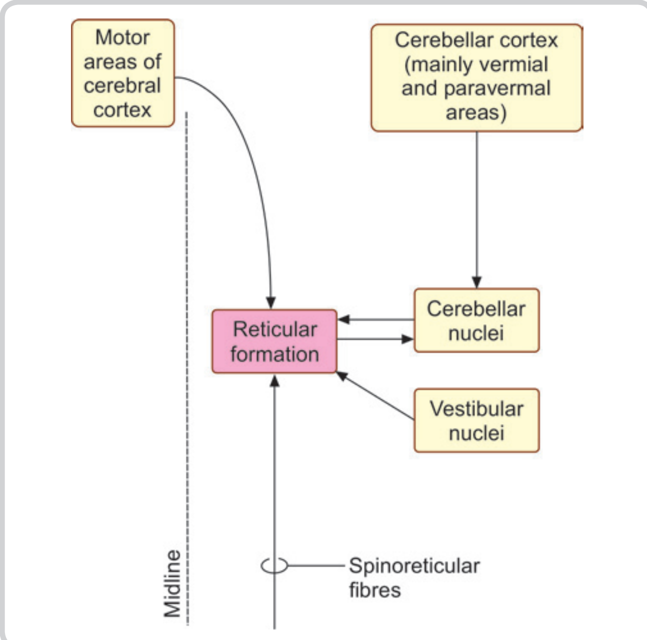

Figure 8.29: Cerebelloreticular connections.

described. Many of the fibres end in relation to neurons of the intermediolateral grey column.

- Descending fibres (from raphe nuclei in the midbrain, pons and medulla) also reach other nuclei of the reticular formation (dorsal tegmental nucleus in the midbrain, and other nuclei in the pons and medulla).
- Fibres from the dorsal raphe nucleus (midbrain) descend to the locus coeruleus.
- The nucleus raphe magnus projects to the caudal part of the spinal nucleus of the trigeminal nerve and influences perception of pain through the nucleus.
- Ascending serotoninergic fibres take origin mainly from the dorsal raphe nucleus, and from the superior central nucleus. The fibres ascend as a large ventral bundle, and a much smaller dorsal bundle. On their journey upward many of the fibres pass through the medial forebrain bundle. Some traverse the fornix, and the stria terminalis. The centres these fibres reach include the following:
  - ***Midbrain:*** Substantia nigra, central grey matter
  - ***Diencephalon:*** Hypothalamus and mammillary body, thalamus, habenular nuclei
  - ***Basal nuclei:*** Caudate nucleus, putamen, amygdala
  - ***Cerebral cortex:*** Limbic, septal and olfactory areas; parts of neocortex

Locus Coeruleus and Noradrenergic System

The locus coeruleus is an area in the floor of the fourth ventricle, at the upper end of the sulcus limitans. The area has a bluish colour caused by the presence of pigment in the underlying neurons. These neurons constitute the nucleus coeruleus.

With the development of techniques for localization of neuropeptides in neurons and their processes, it has been found that the locus coeruleus contains noradrenergic neurons. It lies at the heart of an extensive system of noradrenergic fibres permeating the brain. Apart from the locus coeruleus, noradrenergic neurons are located in the nuclei forming the lateral column of the reticular formation; in the median eminence; and in some other situations. The fibres of the noradrenergic system are ascending and descending:

Descending Fibres

Descending fibres travel to the pontine nuclei, reticular formation of the medulla, and several cranial nerve nuclei (cochlear nuclei, nucleus of tractus solitarius, spinal nucleus of trigeminal nerve, dorsal nucleus of vagus). Fibres descend into the spinal cord in the anterior and lateral funiculi. These fibres terminate in both the dorsal and ventral grey columns, and specially in relation to neurons giving origin to the sacral parasympathetic outflow.

Ascending Fibres

Ascending noradrenergic fibres permeate into many parts of the brain. Within the midbrain they reach the colliculi and the central grey matter. Some fibres reach the cerebellum (cortex as well as cerebellar nuclei).

Fibres ascending into the cerebral hemisphere travel through many fibre bundles mentioned elsewhere. They include the central tegmental tract, medial and lateral longitudinal striae, stria terminalis, fornix, mammillothalamic tract and the diagonal band of Broca. The areas receiving the noradrenergic fibres include the following:

- ***In the diencephalon:*** Thalamus, hypothalamus, habenular nuclei and interpeduncular nucleus
- ***In the telencephalon:*** Parts of neocortex; limbic cortex including the cingulate gyrus, the parahippocampal gyrus and the hippocampus; septal areas, anterior perforated substance, olfactory bulb and anterior olfactory nucleus.

Summary of Functions of the Reticular Formation

Because of its diverse connections the reticular formation is believed to have a controlling or modifying influence on many functions. Some of them are given below:

- ***Somatomotor control:*** Through its direct connections with the spinal cord; and indirectly through the corpus striatum, the cerebral cortex and the cerebellum, the reticular formation has an influence on fine control of movements including those involved in postural adjustments, locomotion, skilled use of the hands, speech, etc.

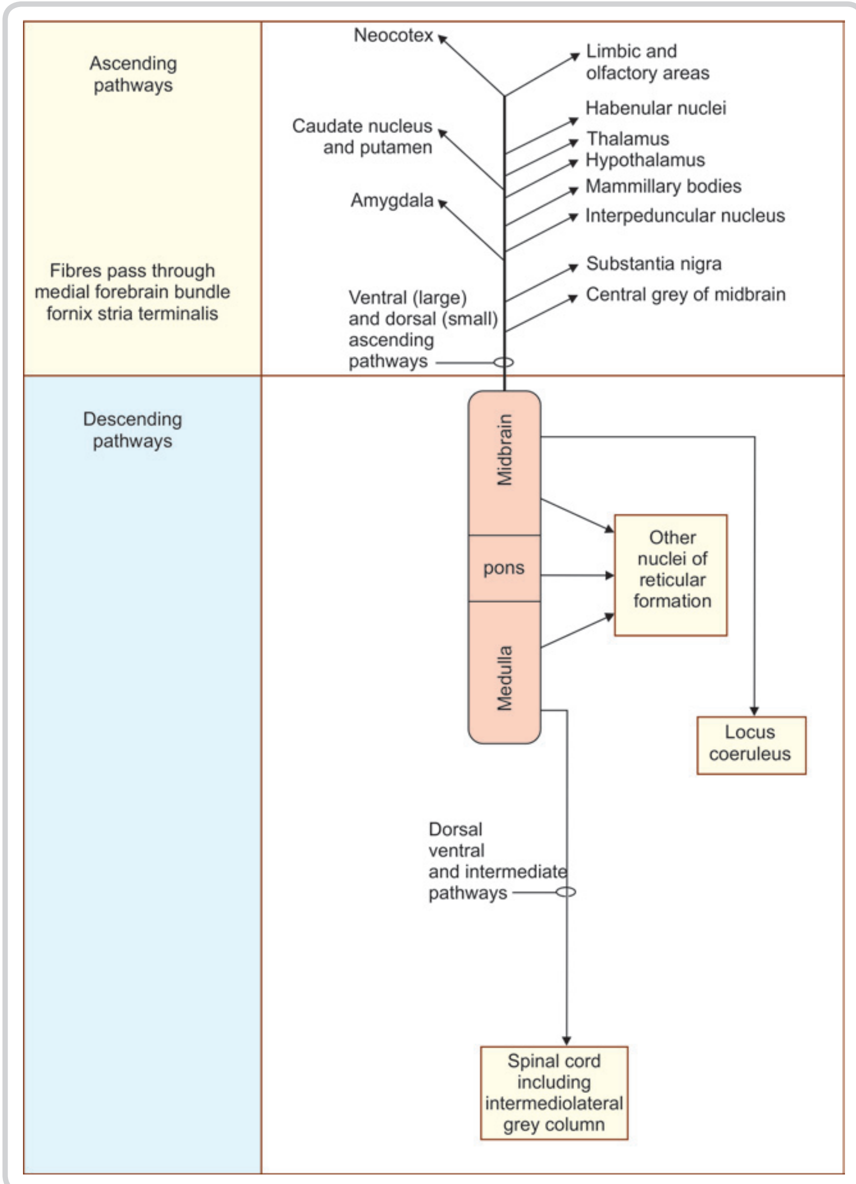

Figure 8.30: Simplified scheme of the serotoninergic system of the central nervous system

- ***Somatosensory control:*** The reticular formation influences conduction through somatosensory pathways. Similar effects may also be exerted on visual and auditory pathways.
- ***Visceral control:*** Physiological studies have shown that stimulation of certain areas in the reticular formation of the medulla has great influence on respiratory and cardiovascular function. The region influencing respiratory activity corresponds approximately to the gigantocellular nucleus and parvocellular nucleus. Stimulation of the gigantocellular nucleus and the upper part of the ventral reticular nucleus causes depression of vasomotor activity while stimulation of other areas has a pressor effect. These effects are through connections between the reticular formation and autonomic centres in the brainstem and spinal cord, but the pathways concerned are not well-defined.
- ***Neuroendocrine control:*** Through its connections with the hypothalamus, the reticular formation influences the activity of the adenohypophysis and of the neurohypophysis.
  A similar influence is also exerted on the pineal body.
- The reticular formation also influences other hypothalamic functions. These include a possible effect on circadian rhythms.
- The significance of the reticular formation in controlling arousal and the state of consciousness through the ascending reticular activating system has been mentioned above.

Functions attributed to the Serotoninergic System include the following:

- Fibres descending dorsally in the spinal cord may form part of a pain controlling pathway. They terminate mainly in the posterior grey column. Cranially, this pathway connects to some centres in the midbrain that constitute a pain control centre (periaqueductal grey, dorsal raphe nucleus and cuneiform nuclei).
- The "intermediate" fibres descending into the spinal cord influence sympathetic control of the cardiovascular system.
- Ventrally descending fibres influence ventral horn cells to which they are facilitatory.
- Ascending serotoninergic fibres influence the activities of the areas to which they project, mainly those of the limbic and related areas.

Functions of the Noradrenergic System

They are not well understood. The system probably plays a role in the control of cardiovascular, respiratory and gastrointestinal functions. It may have a role in circadian rhythms (including the sleep-waking cycle).

Multiple Choice Questions

1. Which of the following tracts decussates at the level of superior colliculus of midbrain?
   A. Dentatothalamic
   B. Cerebellorubral
   C. Tectospinal
   D. Medial longitudinal fasciculus

2. If a patient presents with left sided hemiplegia and right sided lateral squint, the lesion is likely to be at the level of
   A. Right lower pons
   B. Left upper midbrain
   C. Right upper midbrain
   D. Left lower pons

3. The structure separating the basilar and tegmental parts of the pons is
   A. Substantia nigra
   B. Trapezoid body
   C. Vestibular nucleus
   D. Stria medullares

4. The fibres that decussate in the trapezoid body originate from which of the following nuclei?
   A. Arcuate
   B. Vestibular
   C. Inferior olivary
   D. Cochlear

5. The fibres passing through the middle cerebellar peduncle originate from
   A. Pontine nuclei
   B. Tectum
   C. Spinal cord
   D. Spinal trigeminal nucleus

6. Frontopontine fibres pass through which part of midbrain?
   A. Dorsal tegmentum
   B. Medial part of crus cerebri
   C. Ventral tegmentum
   D. Lateral part of crus cerebri

Answers

1. C **2.** C **3.** B **4.** D **5.** A **6.** B

Chapter 9

Cranial Nerves – Nuclei and Functional Components

Specific Learning Objectives

At the end of learning, the student shall be able to:
- Describe the location of nuclei and functional components of twelve cranial nerves
- Describe the cortical control of cranial nerve nuclei supplying skeletal muscles
- Describe the control of eye movements
- Specify the connections and functions of medial longitudinal fasciculus
- Describe testing and clinical anatomy of the twelve cranial nerves

INTRODUCTION

A peripheral nerve may be motor (efferent), sensory (afferent), or mixed (efferent and afferent). They may supply soma (somatic) or viscera (visceral). Thus, functionally, a spinal nerve has four functional components—**(1)** somatic efferent, **(2)** visceral efferent, **(3)** somatic afferent and **(4)** visceral afferent.

Cranial nerves, in addition, supply muscles of pharyngeal arches (special visceral efferent), and carry visceral and somatic special senses, making a total of seven functional components (four general, mentioned above, and three special). No spinal nerve carries special functional components.

There are 12 pairs of cranial nerves:

I	–	Olfactory
II	–	Optic
III	–	Oculomotor
IV	–	Trochlear
V	–	Trigeminal
VI	–	Abducent
VII	–	Facial
VIII	–	Vestibulocochlear
IX	–	Glossopharyngeal
X	–	Vagus (vago-accessory)
XI*	–	Spinal accessory
XII	–	Hypoglossal

* The eleventh cranial nerve is traditionally described as 'accessory' which has a cranial part and spinal part. The cranial accessory is the motor (branchiomotor) part of vagus (hence vago-accessory). The spinal accessory is an independant nerve.

Developmental Aspects

In the embryo, the nuclei related to the various components are arranged in vertical rows (or columns) in a definite sequence in the grey matter related to the floor of the fourth ventricle (Figure 9.1). The sequence is easily remembered, if the following facts are kept in mind:
- Each half of the floor of the ventricle is divided into a medial part and a lateral part by the ***sulcus limitans. Efferent nuclei*** lie in the medial part (called the ***basal lamina***) and ***afferent nuclei*** in the lateral part (called the ***alar lamina***) (Table 9.1).
- In each part (medial or lateral), ***visceral nuclei*** lie nearer the sulcus limitans than ***somatic nuclei.***
- Within each category (for example, visceral efferents, somatic afferents, etc), the ***general nucleus*** lies nearer the sulcus limitans than the ***special nucleus.***

Thus, in proceeding laterally from the midline, the sequence of nuclear columns is as follows:
- Somatic efferent: This column is not subdivided into general and special parts
- Special visceral (or branchial) efferent
- General visceral efferent
- General visceral afferent
- Special visceral afferent
- General somatic afferent
- Special somatic afferent

Each functional component has its own nuclei of origin (in the case of efferent fibres) or termination (in the case of afferent fibres).

As development proceeds, parts of these columns disappear, so that each of them no longer extend to the whole length of the brainstem, but is represented by

Table 9.1 | Nuclear Columns in Basal and Alar Lamina

Nuclear columns of basal lamina	Nuclear columns of alar lamina
Somatic efferent	General visceral afferent
Special visceral efferent	Special visceral afferent
General visceral efferent	General somatic afferent
	Special somatic afferent

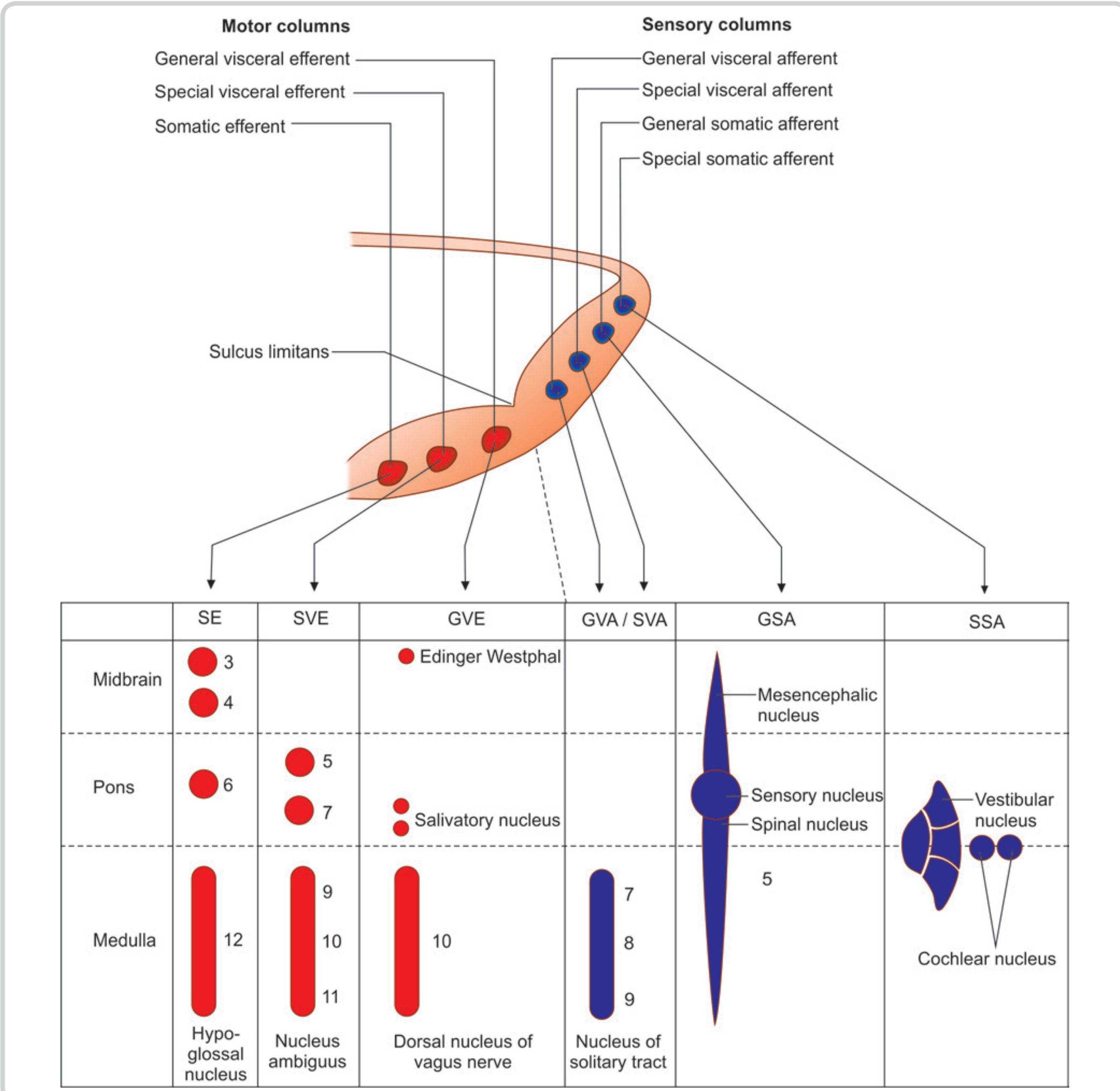

Figure 9.1: Functional classification of cranial nerve nuclei – The upper figure shows the arrangement of nuclear columns in the brainstem of the embryo. The lower figure shows the nuclei derived from each column. Numbers indicate the cranial nerves connected to the nuclei. Note that basal lamina consists of motor cell columns: Somatic efferent (SE), special visceral efferent (SVE), and general visceral efferent (GVE), and alar lamina contain sensory columns: general visceral afferent (GVA), special visceral afferent (SVA), general somatic afferent (GSA), and special somatic afferent (SSA).

one or more discrete nuclei. These nuclei are shown schematically in the lower half of Figure 9.1. Some nuclei retain their original positions in relation to the floor of the fourth ventricle, but some others migrate deeper into the brainstem. The position of the nuclei relative to the posterior surface of the brainstem is illustrated in Figure 9.2. The positions of the nuclei as seen in transverse sections of the brainstem are shown in Figure 9.3.

The olfactory and the optic nerves are not true nerves. They are extensions of telencephalon and diencephalon, respectively. They carry the cavity of the brain (which secondarily gets obliterated) and the meninges with them. They are not covered by Schwann cells. The myelinated parts of the pathways are formed by oligodendrocytes.

In the description that follows, the nuclei of the third to twelfth cranial nerves are considered as they are located in

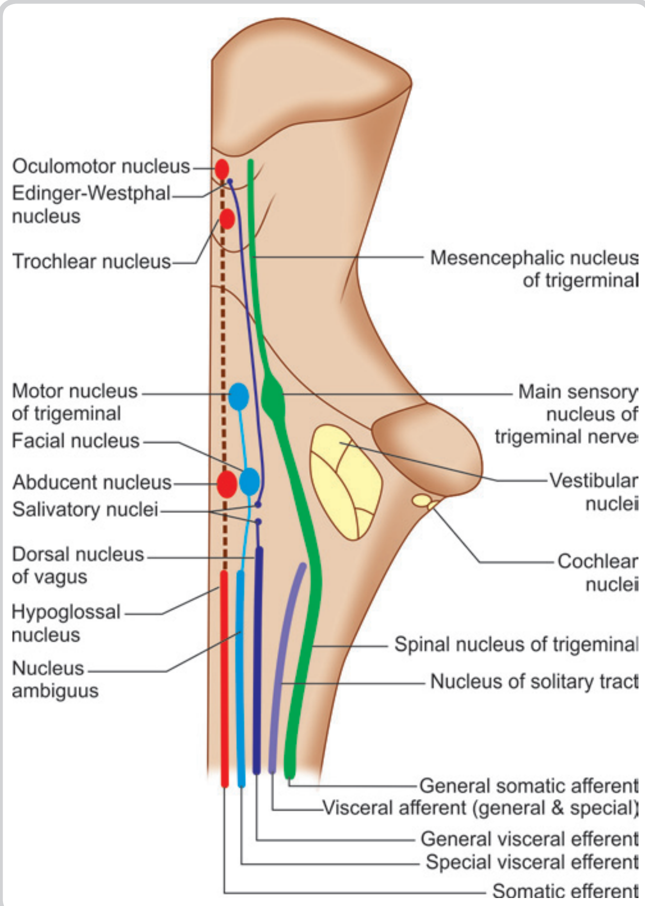

Figure 9.2: Cranial nerve and nuclei as projected onto the dorsal aspect of the brainstem

the brainstem. The cranial nerves III and IV belong to the midbrain, V, VI, VII, and part of VIII to the pons; and the remaining to the medulla.

The functional components of cranial nerve nuclei are shown in Table 9.2. It should be noted that some of these nuclei contribute fibres for more than one nerve. Similarly, some of the cranial nerves consist of fibres arising from more than one nucleus.

SOMATIC EFFERENT NUCLEI

The somatic efferent column consists of the following nuclei that supply striated (skeletal) muscles of somatic origin:

- The ***oculomotor nucleus*** is situated in the upper part of the midbrain at the level of the superior colliculus (Figures 9.1, 9.2, and 9.3F). The nuclei of the two sides form a single complex that lies in the central grey matter, ventral to the aqueduct.
- The ***trochlear nucleus*** is situated in the lower part of the midbrain at the level of the inferior colliculus (Figures 9.1, 9.2, and 9.3E). The nucleus lies ventral to the aqueduct in the central grey matter.
- The ***abducent nucleus*** is situated in the lower part of the pons. It lies in the grey matter lining the floor of the fourth ventricle near the midline (Figures 9.1, 9.2, and 9.3C).
- The ***hypoglossal nucleus*** lies in the medulla. It is an elongated column extending into both the open and closed parts of the medulla. Its upper part lies deep to the hypoglossal triangle in the floor of the fourth ventricle. When traced caudally, it lies next to the midline in the central grey matter, ventral to the central canal (Figures 9.1, 9.2, and 9.3 A and B).

SPECIAL VISCERAL EFFERENT NUCLEI

These nuclei are also called branchial efferent or branchiomotor nuclei. They supply striated (skeletal) muscle derived from the branchial arches.

Table 9.2 | The Functional Nuclear Columns and Cranial Nerve Nuclei of Brainstem

	Motor (Efferent)			Sensory (Afferent)		
	SE	**SVE**	**GVE**	**GVA/SVA**	**GSA**	**SSA**
Midbrain	(III) Oculomotor (IV) Trochlear		Edinger–Westphal nucleus		(V) Mesencephalic nucleus of trigeminal nerve	
Pons	(VI) Abducent	(V) Motor nucleus of trigeminal nerve (VII) Facial	Salivatory nuclei (VII, IX)		(V) Sensory nucleus of trigeminal nerve	(VIII) Vestibulo-cochlear nuclei
Medulla	(XII) Hypoglossal nucleus	(IX, X, XI) Nucleus ambiguus	(X) Dorsal nucleus of vagus	Nucleus of the solitary tract	(V) Nucleus of the spinal tract of the trigeminal nerve	(VIII) Vestibulo-cochlear nucleus

Abbreviations: GVA, general visceral afferent; SVA, special visceral afferent; GSA, general somatic afferent; SSA, special somatic afferent; GSE, general somatic efferent; SVE, special visceral efferent; GVE, general visceral efferent.

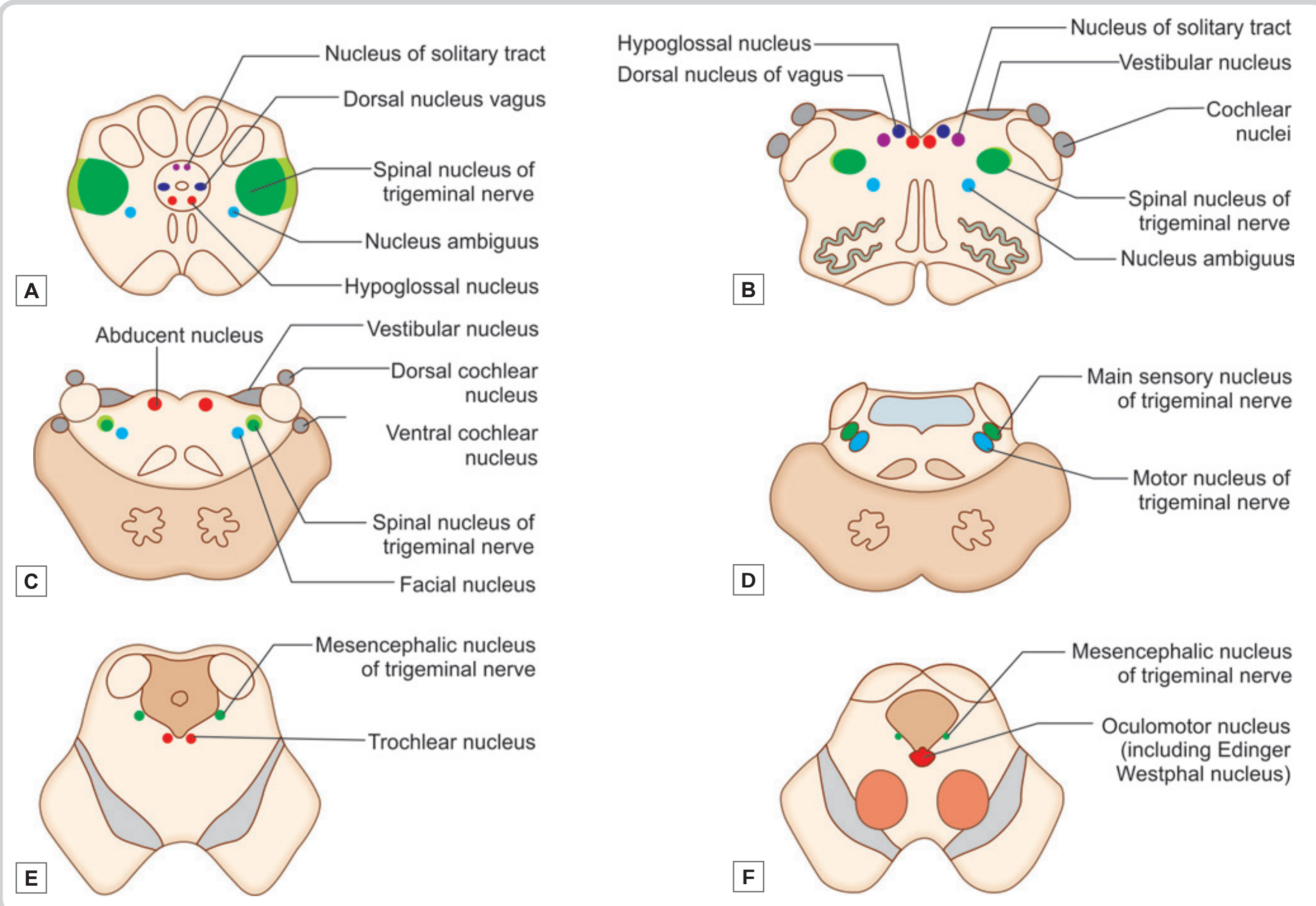

Figure 9.3: Location of cranial nuclei as seen in transverse sections at various levels of the brainstem

- The ***motor nucleus of the trigeminal nerve*** lies in the upper part of the pons, in its dorsal part (Figures 9.1, 9.2, and 9.3D). It is situated in the lateral part of the reticular formation, medial to the main sensory nucleus of the trigeminal nerve.
- The ***nucleus of the facial nerve*** lies in the lower part of the pons and occupies a position similar to that of the motor nucleus of the trigeminal nerve. The spinal nucleus and tract of the trigeminal nerve lie lateral to it (Figures 9.1, 9.2, and 9.3C).
- The ***nucleus ambiguus*** lies in the medulla. It forms an elongated column lying deep in the reticular formation, both in the open and closed parts of the medulla (Figures 9.1, 9.2, and 9.3A and B). Inferiorly, it is continuous with the spinal accessory nucleus. It is a composite nucleus and contributes fibres to the glossopharyngeal, vagus, and accessory nerves.

The ***somatic efferent*** and ***special visceral efferent nuclei*** of cranial nerves supply striated (skeletal) muscle. Their connections are, therefore, similar to those of ventral horn cells of the spinal cord (Figure 9.4). These nuclei are under cortical control through corticonuclear fibres (Table 9.3).

The nuclei are also influenced by other centres, namely the tectum, the red nucleus, and the reticular formation. The cerebellum, diencephalon, and corpus striatum can influence the nuclei through these centres.

The motor nuclei also receive afferents from sensory nuclei of the brainstem, including the nucleus of tractus solitarius and the nucleus of spinal tract of the trigeminal nerve. The motor nucleus of the trigeminal nerve receives some fibres from the mesencephalic nucleus. These fibres form part of the pathway for the jaw jerk.

GENERAL VISCERAL EFFERENT NUCLEI

The nuclei of this column give origin to preganglionic fibres that constitute the cranial parasympathetic outflow. These fibres end in the peripheral ganglia. Postganglionic fibres arising in these ganglia supply smooth muscle or glands. The nuclei are as follows:

- The ***Edinger-Westphal nucleus*** (or ***accessory oculomotor nucleus***) lies in the midbrain (Figures 9.1, 9.2, and 9.3F). It is closely related to the oculomotor complex. Fibres arising in this nucleus pass through the oculomotor nerve. They relay in the ciliary ganglion to supply the sphincter pupillae and the ciliaris muscle.

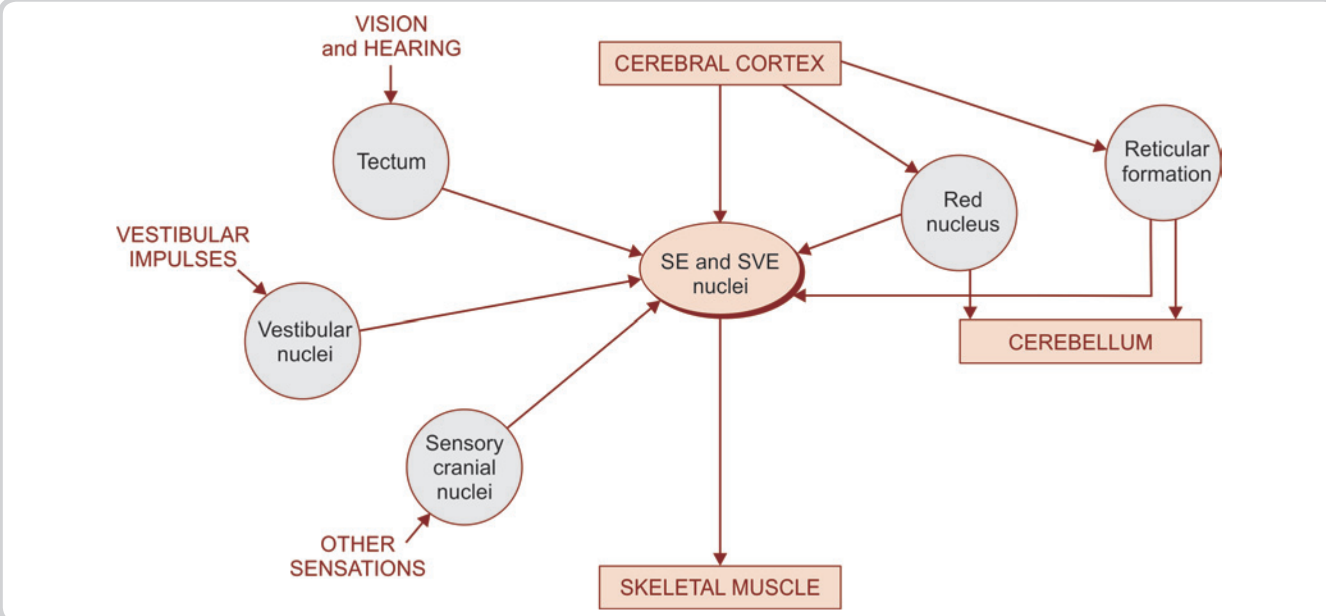

Figure 9.4: Scheme to show the connections of somatic efferent and special visceral efferent nuclei
SE, somatic efferent; SVE, special visceral efferent

Table 9.3 | Cortical Control of Nuclei Supplying Skeletal Muscles

S no	Nucleus	Cortical control[a]
1	Oculomotor (all muscles except medial rectus)	Bilateral
2	Oculomotor (medial rectus)[b]	Ipsilateral
3	Trochlear	Bilateral
4	Trigeminal	Bilateral
5	Abducens	Contralateral
6	Facial (supplying upper face)	Bilateral
7	Facial (supplying lower face)	Contralateral
8	Glossopharyngeal	Bilateral
9	Vagus (including cranial accessory)	Bilateral
10	Spinal accessory (supplying sternocleidomastoid)[c]	Ipsilateral
11	Spinal accessory (supplying trapezius)	Contralateral
12	Hypoglossal	Bilateral

(a) Cortical / capsular hemiplegia, normally, does not paralyse eye movements, jaw movements, soft palate, pharynx, larynx and tongue. If they do get affected, then there would be a history of an earlier hemiplegia / hemiparesis of the opposite side which had subsequently resolved. The new lesion suddenly unmasks the loss of cortical control for the bilaterally-controlled cranial nerve nuclei concerned.

(b) Medial rectus acts conjugately with opposite lateral rectus to cause the eye to move to the opposite side. However, during convergence (for accommodation), medial rectus is controlled by the cortex bilaterally.

(c) The apparent contradiction of cortical control for sternocleidomastoid is evident in capsular hemiplegia. Sternocleidomastoid turns the head to the opposite side. If the sternocleidomastoid were controlled by the opposite cortex (like limb muscles), then during hemiplegia, the unopposed pull of the normal sternocleidomastoid would cause the head to turn away from the (only) normal side! Also, in convulsions originating from frontal lobe, the eyes and the head look (turn) towards the affected limbs!

- The ***salivary*** (or ***salivatory***) ***nuclei*** (superior and inferior) lie in the dorsal part of the pons, just above its junction with the medulla (Figures 9.1 and 9.2). They are located just above the upper end of the dorsal nucleus of the vagus nerve. The superior nucleus sends fibres into the facial nerve. These relay in the submandibular ganglion to supply the submandibular and sublingual salivary glands. The inferior nucleus sends fibres into the glossopharyngeal nerve. These fibres relay in the otic ganglion to supply the parotid gland.

Other neurons probably located near the salivary nuclei (lacrimatory) send out fibres that supply the lacrimal gland, after relaying in the pterygopalatine ganglion. These fibres travel through the facial nerve.

- The ***dorsal (motor) nucleus of the vagus*** (or ***dorsal vagal nucleus***) lies in the medulla. It is a long nucleus lying vertically. Its upper end lies deep to the vagal triangle in the floor of the fourth ventricle. When traced downwards, it extends into the closed part of the medulla where it lies in the lateral part of the central grey matter (Figures 9.1, 9.2, and 9.3 A and B). Fibres arising in this nucleus supply the heart, lungs, bronchi, oesophagus, stomach, small intestine, and large intestine up to the right two-thirds of the transverse colon. They end in ganglia (or nerve plexuses) closely related to these organs. Postganglionic fibres arise in these ganglia and run a short course to supply smooth muscle and glands in these organs.

The ***salivatory*** and ***dorsal vagal nuclei*** receive afferents from sensory cranial nerve nuclei; in particular from the nucleus of the solitary tract. Visceral sensations may also reach these nuclei through collaterals from ascending tracts. The nuclei are connected with the reticular formation. Higher control is exercised by the hypothalamus. The cerebral cortex (specially the limbic lobe) and the thalamus influence the nuclei through the hypothalamus.

GENERAL AND SPECIAL VISCERAL AFFERENT NUCLEI

Both these columns are represented by the ***nucleus of the solitary tract***, present in the medulla (Figures 9.1 and 9.2). Like other cranial nerve nuclei of the medulla, the cells of this nucleus form an elongated column lying deep in the reticular formation. Its upper part lies ventrolateral to the dorsal nucleus of the vagus (Figure 9.3B). When traced downwards, it extends into the closed part of the medulla; here, it lies dorsomedial to the vagal nucleus (Figure 9.3A).

Fibres of taste (special visceral afferent) carried by the facial, glossopharyngeal, and vagus nerves end in the upper part of the nucleus of the solitary tract**.** The nuclear terminations of VII, IX, and X nerves are in rostrocaudal direction. The lower portion of the nucleus receives the general visceral sensations from pharynx (glossopharyngeal and vagus) and from oesophagus and abdominal part of alimentary canal up to right two-thirds of the transverse colon (vagus). The axons from nucleus of tractus solitarius project to the thalamus of the opposite side through the ***solitariothalamic***.

GENERAL SOMATIC AFFERENT NUCLEI

The general somatic afferent column is represented by the three sensory nuclei of the trigeminal nerve. These are as follows:

- The ***main*** (or ***principal***) ***sensory nucleus*** lies in the upper part of the pons in the lateral part of the reticular formation. It lies lateral to the motor nucleus of the trigeminal (Figures 9.1, 9.2, and 9.3D). It is mainly concerned in mediation of proprioceptive impulses, touch, and pressure (from the region to which the trigeminal nerve is distributed).
- The ***nucleus of spinal tract of trigeminal nerve*** (abbreviated, as ***spinal nucleus*)** extends from the main nucleus down into the medulla (Figures 9.1, 9.2 and 9.3 A, B, C) and into the upper two segments of the spinal cord. Its lower end is continuous with the substantia gelatinosa of the spinal cord. In addition to the fibres of the trigeminal nerve, the nucleus also receives general somatic sensations carried by the facial, glossopharyngeal and vagus nerves.

  The spinal nucleus is concerned mainly with the mediation of pain and thermal sensibility. Different parts of the nucleus correspond to different areas innervated. The spinal nucleus is divisible (cranio-caudally) into three subnuclei (***oralis, interpolaris and caudalis***) for mandibular, maxillary and ophthalmic divisions of trigeminal nerve, respectively.
- The ***mesencephalic nucleus*** of the trigeminal nerve extends cranially from the upper end of the main sensory nucleus into the midbrain. Here it lies in the central grey matter lateral to the aqueduct (Figure 9.3 E, F). Functionally, this nucleus appears to be similar to sensory ganglia of cranial nerves, and to the spinal ganglia, rather than to afferent nuclei. The neurons in it are pseudounipolar. The peripheral processes of these neurons carry proprioceptive impulses from muscles of mastication, and possibly also from muscles of the eyeballs, face and tongue. The central processes of the neurons in the nucleus end in the main sensory nucleus of the trigeminal nerve. The mesencephalic nucleus is the centre for the jaw jerk.

The neurons in the main sensory and spinal nuclei of the trigeminal nerve are second order neurons. Their axons are comparable to the fibres of the spinothalamic tracts. The axons cross to the opposite side and form a bundle called the ***trigeminal lemniscus*** (Figure 9.5). This lemniscus ascends to the thalamus (ventral posteromedial nucleus). Third order neurons located in the thalamus carry the sensations to the sensory areas of the cerebral cortex (Figure 9.6). In the pons and midbrain the trigeminal lemniscus lies immediately lateral to the medial lemniscus. Its fibres are closely related to those of the spinal lemniscus (lateral spinothalamic tract).

SPECIAL SOMATIC AFFERENT NUCLEI

These are the ***cochlear*** and ***vestibular nuclei***.

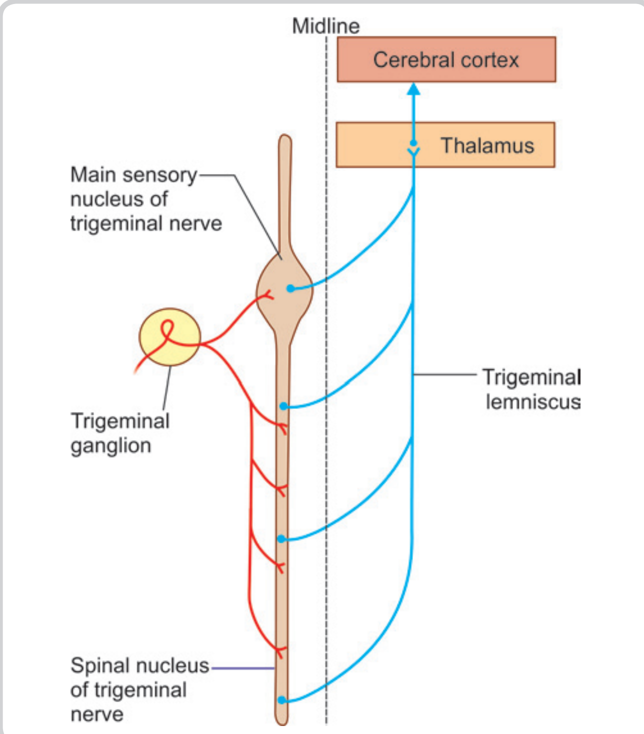

Figure 9.5: Connections of the sensory nuclei of the trigeminal nerve

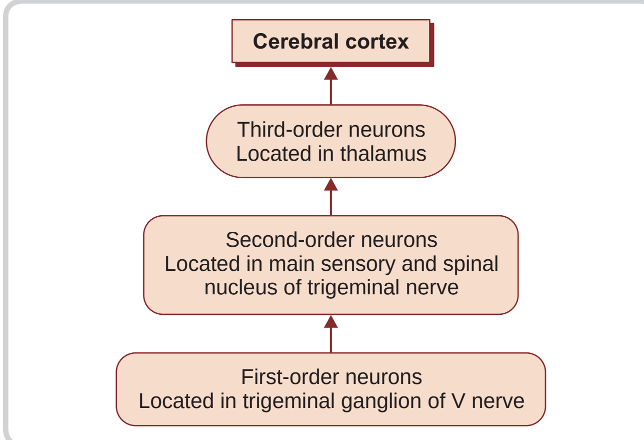

Figure 9.6: Flow diagram showing the neurons involved in carrying general somatic sensations from the trigeminal nerve to the cerebral cortex

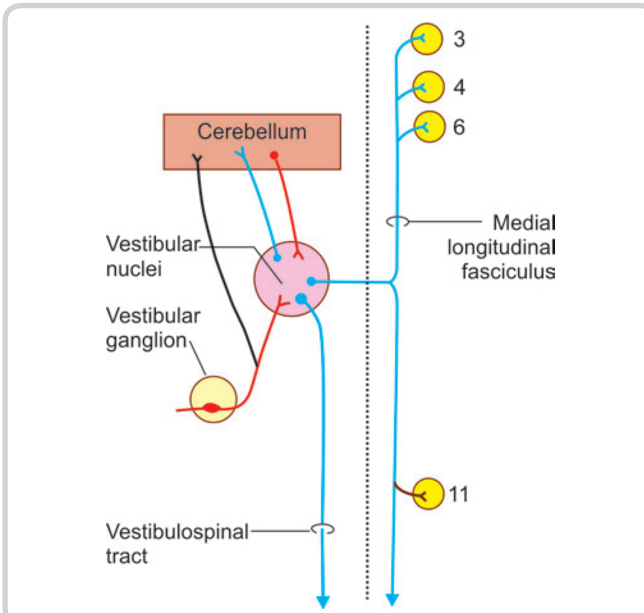

Figure 9.7: Connections of the vestibular nuclei

Cochlear Nuclei

The cochlear nuclei are two in number, dorsal and ventral. They are placed dorsal and ventral, respectively to the inferior cerebellar peduncle (Figure 9.3B and C) at the level of the junction of the pons and medulla. The two nuclei are continuous, being separated only by a layer of nerve fibres. Additional details are given in Chapter 10.

Vestibular Nuclei

The vestibular nuclei lie in the grey matter underlying the lateral part of the floor of the fourth ventricle (Figure 9.3 B and C). They lie partly in the medulla and partly in the pons. Four distinct nuclei are recognized. These are medial, lateral, inferior, and superior. The lateral nucleus is also called as ***Dieter's nucleus***.

Connections of Vestibular Nuclei

The vestibular nuclei receive the following afferents (Figure 9.7):

- The main afferents are central processes of bipolar neurons of the vestibular ganglion. These fibres constitute the vestibular part of the vestibulocochlear nerve. They convey impulses from end organs in the semicircular ducts, utricle, and saccule. These are necessary for maintenance of equilibrium.

  After entering the medulla, the fibres of the vestibular nerve divide into ascending and descending branches. The descending branches end in the medial, lateral, and inferior vestibular nuclei. The ascending branches reach the superior vestibular nucleus.
- The vestibular nuclei also receive fibres from some parts of the cerebellum.

The efferents from the vestibular nuclei are as follows:

- Vestibulocerebellar fibres pass through the inferior cerebellar peduncle. The vestibulocerebellar fibres form a separate bundle, the ***juxtarestiform body***, within the peduncle. Some fibres of the vestibular nerves bypass the vestibular nuclei and go straight to the cerebellum.
- Fibres arising in the vestibular nuclei establish connections with cranial nerve nuclei responsible for

movements of the eyes (third, fourth, and sixth) and of the neck (eleventh). These fibres form the ***medial longitudinal fasciculus (or bundle)***.

- Fibres from the lateral vestibular nucleus descend to the spinal cord as the vestibulospinal tract. Fibres from the medial (and other) nuclei descend to the spinal cord through the medial longitudinal fasciculus. These fibres are sometimes named the ***medial vestibulospinal tract.*** Some fibres reach the pontine reticular formation.
- Some fibres from the vestibular nuclei enter the lateral lemniscus.
- Some vestibular impulses reach the thalamus (ventroposterior nucleus) and are relayed to the cerebral cortex. A vestibular centre is present in the parietal lobe just behind the postcentral gyrus.

MEDIAL LONGITUDINAL FASCICULUS

The medial longitudinal fasciculus (MLF) consists of a bundle of fibres, arising mainly from right and left medial vestibular nuclei in the medulla, that lie near the midline of the brainstem, one on either side. Above, it reaches up to the level of the third ventricle. The ascending fibres end in the interstitial nucleus of Cajal, the nucleus of the posterior commissure, and the nucleus of Darkschewitsch. Fibres of this bundle cross the midline forming the ***posterior commissure*** which is located in the inferior lamella of the pineal stalk. Through this commissure, the vestibular nuclei of both sides are connected.

Below, the medial longitudinal bundle becomes continuous with the anterior intersegmental tract of the spinal cord.

The fasciculus is closely related to the nuclei of the third, fourth, sixth and twelfth cranial nerves (all of the somatic efferent column and lying next to the midline). It is also related to the fibres of the seventh nerve (as they wind around the abducent nucleus), and to some fibres arising from the cochlear nuclei. In the spinal cord it establishes connections with ventral horn cells that innervate the muscles of the neck (Figure 9.8).

The ***functions of the MLF*** are as given below:

- Fibres arise in the vestibular nuclei of the same side as well as those of the opposite side. These fibres ascend or descend in the fasciculus to reach nuclei supplying the muscles of the eyeball and neck. These connections ensure harmonious movements of the eyes and head in response to vestibular stimulation.
- Some fibres of the fasciculus are connected to some nuclei of the auditory pathway. These are the nucleus of the trapezoid body and the nucleus of the lateral lemniscus. Through these connections movements of the head and of the eyes can take place in response to auditory stimuli.
- The medial longitudinal fasciculus affords a pathway for fibres interconnecting the nuclei related to it. Connections between the facial and hypoglossal nuclei facilitate simultaneous movements of the lips and tongue as in speech.

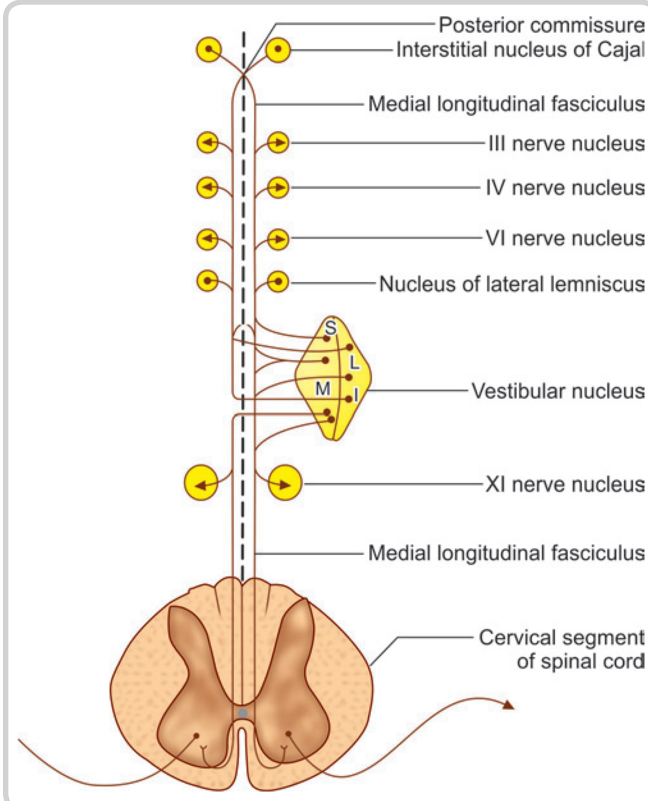

Figure 9.8: Medial longitudinal fasciculus

FUNCTIONAL COMPONENTS OF INDIVIDUAL CRANIAL NERVES

Having considered the cranial nerve nuclei and their connections, it is now possible to work out the functional components of each cranial nerve.

I. Olfactory Nerve

This is the nerve of smell. As the olfactory mucosa is derived from ectoderm (of the nasal placodes), this nerve is classified, developmentally, as ***special somatic afferent*** (along with vision and hearing). However, in view of the close relationship between the sensations of smell and taste, this nerve is functionally classified as **special visceral afferent.**

Clinical Correlation

The olfactory nerve is tested by asking the patient to recognize various odors (coffee, tea, etc). The right and left nerves are tested separately by closing one nostril and putting the substance near the open nostril. Irritants like ammonia should not be used, since they would stimulate the trigeminal nerve that supplies the nasal mucosa. Loss of sense of smell is called ***anosmia*.** Block of the respiratory tract due to excessive secretion of mucus, in common cold, is the most frequent cause. If there is damage to olfactory epithelium (which is a neuroepithelium), it regenerates. This is the only example of neuronal cell body, when damaged which is capable of regeneration.

II. Optic Nerve

This is the nerve of vision. Its fibres are ***special somatic afferent***. From the point of view of its structure and development, this nerve is to be regarded as a tract of the brain rather than as a peripheral nerve.

Clinical Correlation

- ***Acuity (sharpness) of vision*** can be tested by making the patient read letters of various sizes printed on a chart (Snellen's chart) from a fixed distance (six meters). Near vision can be tested by Jaeger charts. Loss of acuity of vision can be caused by errors of refraction, or by the presence of opacities in the cornea or the lens (cataract). Opacities need to be corrected surgically.

  In ***hypermetropia*** (far-sightedness), a biconvex lens corrects the diverging rays, from near objects, so that they are brought to a focus on the retina.

  In ***myopia*** (near-sightedness), a biconcave lens in front of the eye causes the parallel light rays, from far objects, to diverge slightly before striking the eye.

  If the curvature of the cornea is not uniform, called ***astigmatism***, it is corrected with cylindrical lenses placed in such a way that they equalize the refraction in all meridians.

  With advancing age, due to increasing hardness of the lens, there is loss of accommodation, which is known as ***presbyopia***. It is corrected by wearing reading glasses with convex lenses.
- Colour vision can be tested by Ishihara charts. ***Red–green colour blindness*** is an X-linked recessive disorder (both, red cone and green cone gene are encoded on X chromosome, but not the blue cone), while ***blue-yellow colour blindness*** is autosomal recessive.
- Field of vision can be tested by perimetry. Field of vision is tested clinically by keeping the patient's gaze fixed while presenting objects at various places within his visual field. A chart is plotted depicting the patient's field of vision in each eye.

III. Oculomotor Nerve

Functional Components

This nerve has the following components (Figure 9.9):

- ***Somatic efferent*** fibres arising in the oculomotor nucleus supply all extrinsic muscles of the eyeball except the lateral rectus and the superior oblique.
- ***General visceral efferent*** fibres (preganglionic) arise in the Edinger-Westphal nucleus and terminate in the ciliary ganglion. Postganglionic fibres arising in this ganglion supply the sphincter pupillae and the ciliaris muscle.

The general visceral efferent component of the oculomotor nerve is involved in accommodation of lens (for the near vision) and constriction of pupil. The accommodation of lens is due to contraction of ciliary muscles and the constriction of pupils is due to contraction of sphincter pupillae muscle of iris.

IV. Trochlear Nerve

Functional Components

This nerve is made up of ***somatic efferent*** fibres arising in the trochlear nucleus and supplying the superior oblique muscle of the eyeball.

VI. Abducent Nerve

Functional Components

This nerve consists of ***somatic efferent*** fibres that arise from the abducent nucleus and supply the lateral rectus muscle of the eyeball.

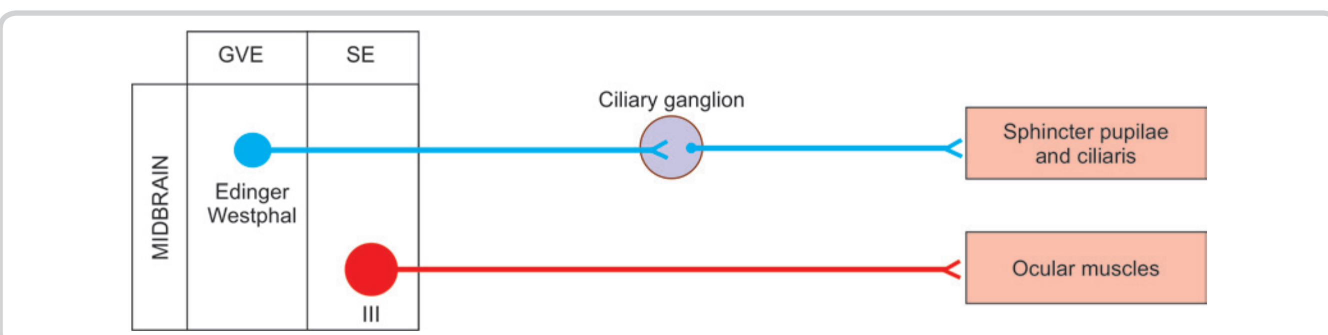

Figure 9.9: Scheme to show the functional components of the oculomotor nerve

CONTROL OF EYE MOVEMENTS

The cranial nerve nuclei that innervate the muscles that move the eyeballs are under the influence of a complex network involving the cerebral cortex, the cerebellum, the superior colliculus, the vestibular nuclei and other centres.

The gross control of ocular movements is similar to that for other movements. The motor area of the cerebral cortex projects to the cranial nerve nuclei concerned through corticonuclear fibres. The nuclei are also influenced by other centres. The final common pathway for ocular movements is by oculomotor, trochlear and abducent nerves.

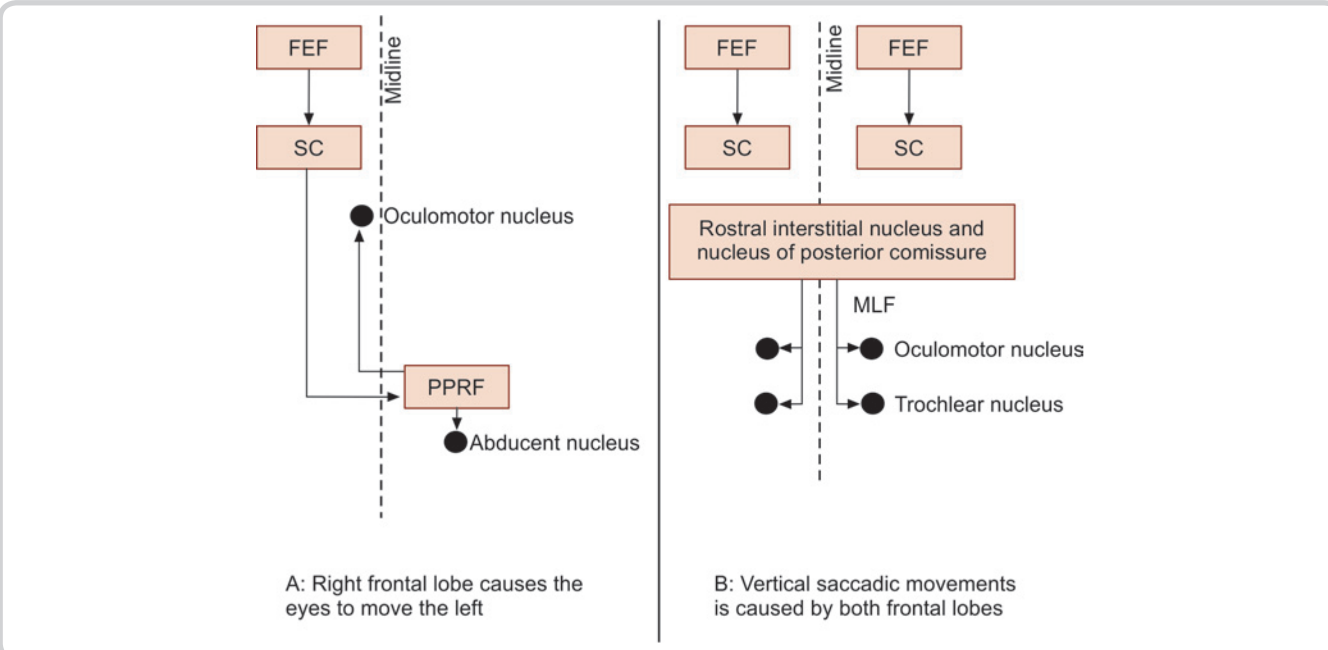

Figure 9.10: A Horizontal saccadic movement B Vertical saccadic movement (FEF = frontal eye field, SC = Superior colliculus, MLF = Medial longitudinal fasciculus, PPRF = Pontine paramedian reticular formation)

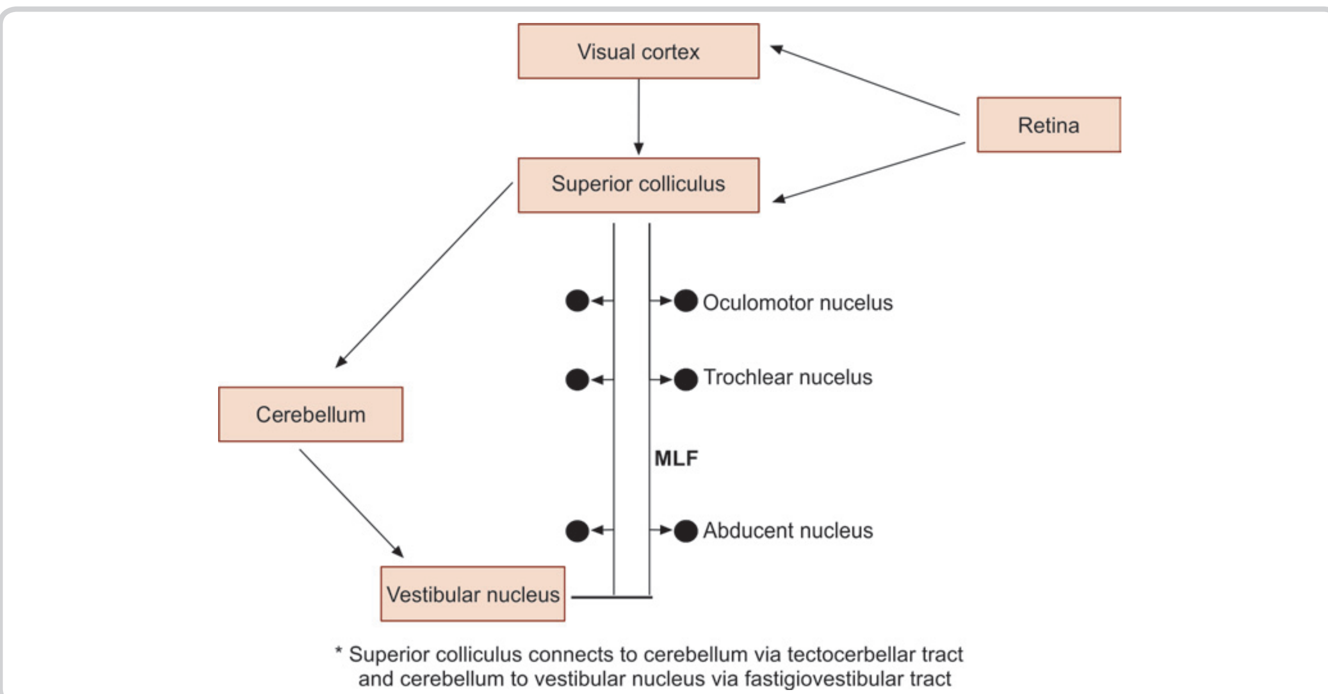

Figure 9.11: Control for smooth pursuit movement (two pathways – superior colliculus directly and via cerebellum)

Types of Movements

- ***Saccadic:*** When the gaze is shifted from one object to another the eyes undergo sharp movements called saccades. The controlling centres determine the velocity and extent of a saccade. The area of cerebral cortex involved in saccadic movements is the frontal eye field (area 8). The cerebral cortex projects to the superior colliculus. The superior colliculus projects to the vertical gaze centre in the midbrain. It is located in the rostral interstitial nucleus (for downward gaze) and nucleus of posterior commissure (for upward gaze). Superior colliculus also projects to the horizontal gaze centre lies in the pons, in the paramedian reticular formation (Figure 9.10).
- ***Smooth pursuit:*** Movements of the eye when the eyes follow a moving object is called as pursuit movement. The area of cerebral cortex involved in pursuit movements is the visual cortex (area 17, 18, 19). The superior colliculus projects both directly and via cerebellum to the cranial nerve nuclei (Figure 9.11).
- ***Vergence:*** A disconjugate movement occurs when the medial recti of both eyes contract. This results in convergence. The visual cortex controls this movement.
- ***Doll's eye movement:*** In as unconscious person (but not brain-dead), when the head is rotated sharply, the eyes move conjugately in the opposite direction. This movement resembles the movement of the eyes of a doll. The centre that controls this movement is vestibular apparatus.

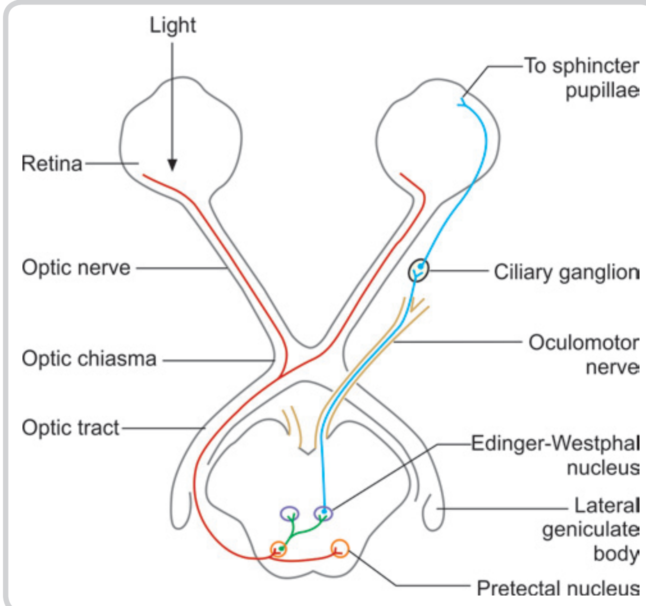

Figure 9.12: Pathway for the light reflex (Note that all structures shown are bilateral Some of them are shown only on one side for sake of clarity)

Clinical Correlation

Oculomotor, Trochlear, and Abducent Nerves

These three nerves are responsible for movements of the eyeball. In a routine clinical examination, the movements are tested by asking the patient to keep his head fixed and to move his eyes in various directions, i.e., upwards, downwards, inwards, and outwards. An easy way is to ask the patient to keep his head fixed and to follow the movements of your finger with his eyes. Such an examination can detect a gross abnormality in movement of the eyes.

Parasympathetic fibres of oculomotor nerve can be tested by examining the pupils for their equality and constriction to light and accommodation.

Reflexes in relation to oculomotor nerve

Normally, both pupils contract when exposed to light in one eye (***pupillary light reflex***). Constriction of ipsilateral pupil is called ***direct light reflex***, while constriction of contralateral pupil is called ***consensual light reflex***. The pupil also contracts when the relaxed eye is made to concentrate on a near object (***accommodation reflex***).

Accommodation reflex involves convergence (voluntary), pupillary constriction and accommodation (involuntary).

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Both these reflexes are lost in oculomotor nerve damage. The power of accommodation is lost because of paralysis of the ciliaris muscle.

The neural pathway for pupillary light reflex is as follows (Figure 9.12):

Retina → optic nerve → optic chiasma → optic tract → superior brachium → midbrain at level of superior colliculus → ***pretectal nucleus*** (midbrain) → *both* Edinger-Westphal nucleus → oculomotor nerve → ciliary ganglion → short ciliary nerves → sphincter pupillae

The neural pathway for convergence reaction is as follows:

Retina → Optic nerve → Optic chiasma → Optic tract → Lateral geniculate body → Optic radiation → Visual cortex → Corticonuclear tract → *Both* oculomotor nucleus → **Medial recti contraction**

(Since this neural pathway involves the cerebral cortex and requires voluntary participation of the patient, it is called convergence reaction. Convergence of the eyeball causes pupillary constriction and contraction of ciliaris, which is called accommodation reflex)

The neural pathway for accommodation reflex is as follows:

Medial recti contraction → proprioception from medial recti → ***nucleus of Perlia*** (midbrain) → *both* Edinger-Westphal nucleus → oculomotor nerve → ciliary ganglion → short ciliary nerves → sphincter pupillae and ciliaris

Damage to the dorsal aspect of rostral midbrain causes loss of constriction of pupils due to pupillary light reflex but not due to accommodation reflex (**Argyll-Robertson** pupils). (Remember: **A**rgyll-**R**obertson **p**upils = **a**ccommodation **r**eflex **p**resent).

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Diplopia and Squint

Sometimes one of the ocular muscles may not be completely paralysed but may be weak. Two indications of such weakness are as follows:

Diplopia

This term means that objects are seen double. To understand this phenomenon, remember that objects lying in different parts of the visual field produce images over different spots on the retina. The brain judges the position of an object by the position at which its image is formed on the retina. Normally the movements of the right and left eyes are in perfect alignment, and an object casts an image on corresponding spots on the two retinae so that only one image is perceived by the brain. When a muscle of the eyeball is weak, and a movement involving that muscle is performed, the movement of the defective eye is slightly less than that of the normal eye. As a result images of the object on the two retinae are not formed at corresponding points but over two points near each other. The brain therefore 'sees' two images, one from each retina.

To understand the causation of diplopia you can do a little experiment on yourself. Fix your gaze on any object. Place a finger below one eyeball and gently push it upwards. In addition to the normal bright image of the object you will see a second fainter image above the normal image. This illustrates that diplopia will be produced by any factor that distorts the normal alignment of the two eyes relative to each other.

Squint (or strabismus)

This is a condition in which the two eyes do not look in the same direction. The squint becomes obvious when the eye movement involves a muscle that is paralysed or weak, because the weak muscle cannot keep up with the muscle of the normal side.

As explained above, squint will be accompanied by diplopia. However, the patient compensates for lack of movement of the eyeball by turning the head in the direction of the object and on doing so the diplopia disappears.

If the normal eye is closed, the patient is unable to judge the position of objects in the field of vision correctly (because the image of the object does not fall on the part of the retina that corresponds to the true position of the object). All the features described above are those of paralytic squint.

There is another type of squint called concomitant squint. This condition is congenital, and manifests itself in early childhood. Concomitant squint also occurs if any wall of the orbit is involved in carcinoma. Squint is present in all positions of the eyeball. There is no muscular weakness and movements are normal in all directions. There is no diplopia because the visual cortex suppresses the image of the defective eye.

Involvement of pathways involved in control of eye movements:

- ***Supranuclear ophthalmoplegia:*** Involvement of frontal lobe or genu of internal capsule results in inability to move the eyeballs to the opposite side. Unopposed action of the opposite cortex results in conjugate rotation towards the side of lesion. Since the movement is conjugate, there is no diplopia. Smooth pursuit movement is unaffected in either direction!
- ***Internuclear ophthalmoplegia:*** Commonly, this is due to the involvement of both medial longitudinal fascicules connecting paramedian pontine reticular formation (PPRF) to oculomotor nuclei because of periaqueductal lesion. At rest, the eyes are conjugate. On attempt to look towards the left, the left lateral rectus contracts but the right medial rectus fails to contract. Similarly, on attempt to look towards the right, the right lateral rectus contracts but the left medial rectus fails to contract.
- ***Infranuclear ophthalmoplegia:*** Involvement of the final common pathway (the oculomotor, trochlear and abducent nerve).

Paralysis of Oculomotor Nerve

All movements of the eyeball are lost in the affected eye. When the patient is asked to look directly forwards, the affected eye is directed laterally (by the lateral rectus) and downwards (by the superior oblique). There is lateral squint (external strabismus) and diplopia. As the levator palpebrae superioris is paralysed, there is drooping of the upper eyelid (ptosis).

As ***parasympathetic fibres*** to the sphincter pupillae pass through the oculomotor nerve, the sphincter pupillae is paralysed. Unopposed action of sympathetic nerves produces a fixed and dilated pupil.

Paralysis of Trochlear Nerve

The superior oblique muscle (supplied by the trochlear nerve) moves the eyeball downwards and laterally, and the inferior rectus (supplied by the oculomotor nerve) moves it downwards and medially. For direct downward movement synchronized action of both muscles is required. When the superior oblique muscle is paralysed the eyeball deviates medially on trying to look downwards.

Paralysis of Abducent Nerve

This nerve supplies the lateral rectus muscle which moves the eyeball laterally. In looking forwards the lateral pull of the lateral rectus is counteracted by the medial pull of the medial rectus and so the eye is maintained in the centre. When the lateral rectus is paralysed the affected eye deviates medially (medial squint, or internal strabismus).

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V. Trigeminal Nerve

Functional Components

This nerve contains the following components (Figure 9.13):

- ***Special visceral efferent*** fibres arise from the motor nucleus of the nerve and supply the muscles of mastication.
- ***General somatic afferent*** fibres of the nerve are peripheral processes of unipolar neurons in the trigeminal ganglion. They carry exteroceptive sensations from the skin of the face and the mucous membrane

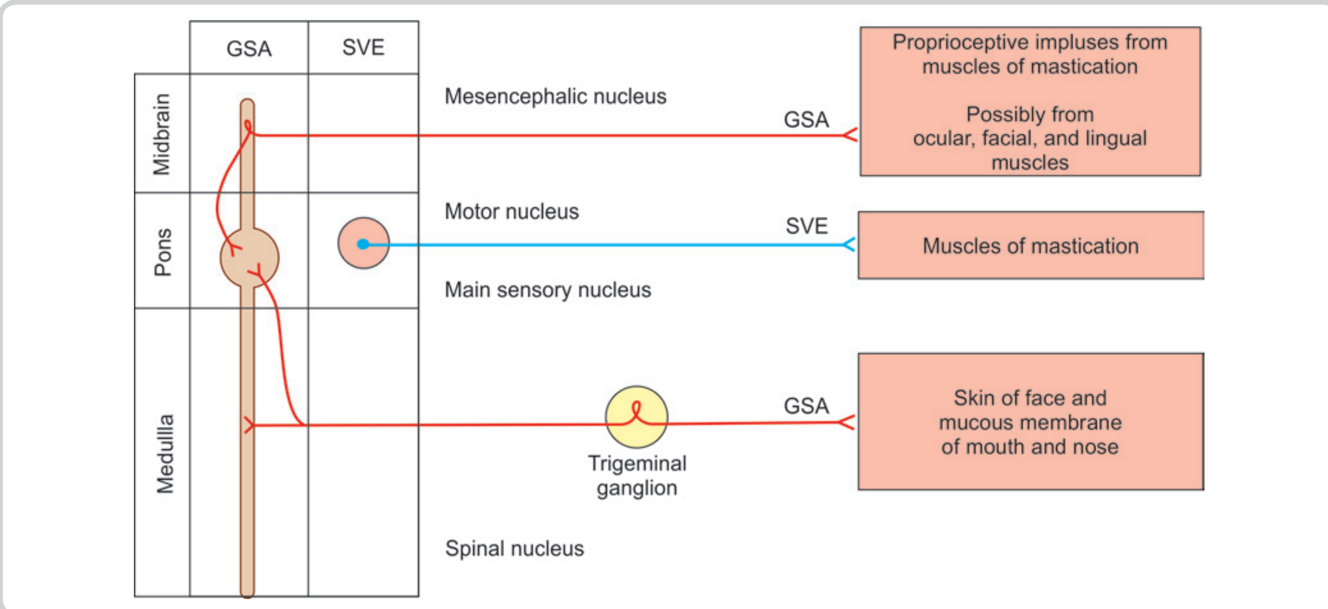

Figure 9.13: Scheme to show the functional components of the trigeminal nerve GSA, general somatic afferent; SVE, special visceral efferent

of the mouth and nose. The central processes of the neurons in the ganglion constitute the sensory root of the nerve. They terminate in the main sensory nucleus and in the spinal nucleus of the nerve.

Another group of general somatic afferent neurons carry proprioceptive impulses from the muscles of mastication (and possibly from ocular, facial, and lingual muscles). These fibres are believed to be peripheral processes of unipolar neurons located in the mesencephalic nucleus of this nerve.

The trigeminal nerve is attached to the ventrolateral surface of the pons by two roots, a very large lateral sensory root and a small medial motor root. Close to the attachment on pons, the sensory root contains a ganglion (trigeminal ganglion). The trigeminal ganglion divides into three branches: ophthalmic, maxillary, and mandibular (Figure 9.14). The ophthalmic and maxillary nerves are sensory nerves, while the mandibular nerve has both motor and sensory fibres.

Clinical Correlation

The trigeminal nerve has a wide sensory distribution. It also supplies the muscles of mastication.

The sensation of touch in the area of distribution of the nerve can be tested by touching different areas of skin with a wisp of cotton wool. The sensation of pain can be tested by gentle pressure with a pin.

Motor function is tested by asking the patient to clench his teeth firmly. Contraction of the masseter can be felt by palpation when the teeth are clenched.

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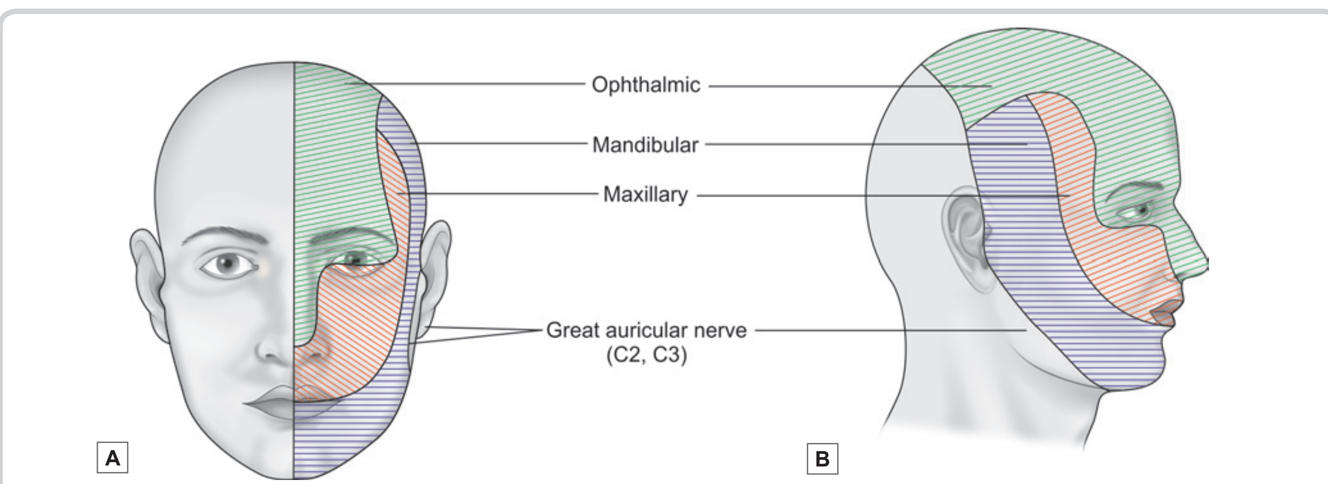

Figure 9.14: Scheme to show the cutaneous territory of three divisions of the trigeminal nerve (**A**) Frontal view and (**B**) Lateral view

Effects of injury or disease

Injury to the trigeminal nerve causes paralysis of the muscles supplied and loss of sensations in the area of supply. Some features of special importance are as follows:

- Apart from their role in opening and closing the mouth, the muscles of mastication are responsible for side-to-side movements of the mandible. Contraction of these muscles on one side moves the chin to the opposite side. Normally, the chin is maintained in the midline by the balanced tone of the muscles of the right and left sides. In paralysis of the pterygoid muscles of one side, the chin is pushed to the paralyzed side by muscles of the opposite side.
- Loss of sensation in the ophthalmic division (specially, the nasociliary nerve) is of great importance. Normally, the eyelids close as soon as the cornea is touched (corneal reflex). Loss of sensation in the cornea abolishes this reflex leaving the cornea unprotected. This can lead to the formation of ulcers on the cornea, which can in turn lead to blindness.
- Pain arising in a structure supplied by one branch of the nerve may be felt in an area of skin supplied by another branch. This is called referred pain. Some examples are as follows:
  - Caries of a tooth in the lower jaw (supplied by the inferior alveolar nerve) may cause pain in the ear (auriculotemporal).
  - If there is an ulcer or cancer on the tongue (lingual nerve), the pain may again be felt over the ear and temple (auriculotemporal).
  - In frontal sinusitis (sinus supplied by a branch from the supraorbital nerve), the pain is referred to the forehead (skin supplied by supraorbital nerve). In fact, headache is a common symptom when any structure supplied by the trigeminal nerve is involved (for example, eyes, ears, and teeth).
- A source of irritation in the distribution of the nerve may cause severe persistent pain (***trigeminal neuralgia***). Removal of the cause can cure the pain. However, in some cases, no cause can be found. In such cases, pain can be relieved by injection of alcohol into the trigeminal ganglion, one of the divisions of the nerve, or into its sensory root. In some cases, it may be necessary to cut fibres of the sensory root. In this connection, it is important to know that the fibres for the maxillary and mandibular divisions can be cut without destroying those for the ophthalmic division. This is possible as the fibres for the ophthalmic division lie separately in the upper medial part of the sensory root. Finally, it may be

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noted that trigeminal pain can also be relieved by cutting the spinal tract of the trigeminal nerve. This procedure is useful, specially for relieving pain in the distribution of the ophthalmic division as pain can be abolished without loss of the sense of touch and, therefore, without the abolition of the corneal reflex.

- ***Mandibular nerve block:*** This is used for anesthesia of the lower jaw (for extraction of teeth). Palpate the anterior margin of the ramus of the mandible. Just medial to it, you will feel the pterygomandibular raphe (ligament). The needle is inserted in the interval between the ramus and the raphe. The tip of the needle is now very near the inferior alveolar nerve, just before it enters the mandibular canal. Anesthetic injected here blocks the nerve.
- The lingual nerve lies very close to the medial side of the third molar tooth, just deep to the mucosa. The nerve can be injured in careless extraction of a third molar. In cases of cancer of the tongue, having intractable pain, the lingual nerve can be cut at this site to relieve pain.

Reflexes Mediated by Trigeminal Nerve

The trigeminal nerve is involved in a number of reflexes summarized in Table 9.4.

VII. Facial Nerve

Functional Components

The components of this nerve are as follows (Figure 9.15):

- ***Special visceral efferent*** fibres begin from the motor nucleus and supply the various muscles to which the nerve is distributed.
- ***General visceral efferent*** fibres (preganglionic) arise in the superior salivary nucleus. They relay in the submandibular ganglion from which postganglionic fibres arise to supply the submandibular and sublingual salivary glands.

  The facial nerve also carries general visceral efferent fibres for the lacrimal gland. The preganglionic neurons concerned are said to be located near the salivary nuclei. Their axons terminate in the pterygopalatine ganglion, from which postganglionic fibres arise to supply the gland.
- ***Special visceral afferent*** fibres are peripheral processes of cells in the geniculate ganglion of the nerve. They supply taste buds in the anterior two-thirds

Table 9.4 | Important Reflexes Mediated by the Trigeminal Nerve

Reflex	Afferent Limb	Efferent Limb
Corneal reflex	Ophthalmic nerve	Facial nerve
Conjunctival reflex	Ophthalmic / maxillary nerve	Facial nerve
Lacrimation reflex	Ophthalmic nerve	Facial nerve
Sneezing reflex	Maxillary nerve	Vagus nerve
Jaw-jerk (masseteric) reflex	Mandibular nerve	Mandibular nerve

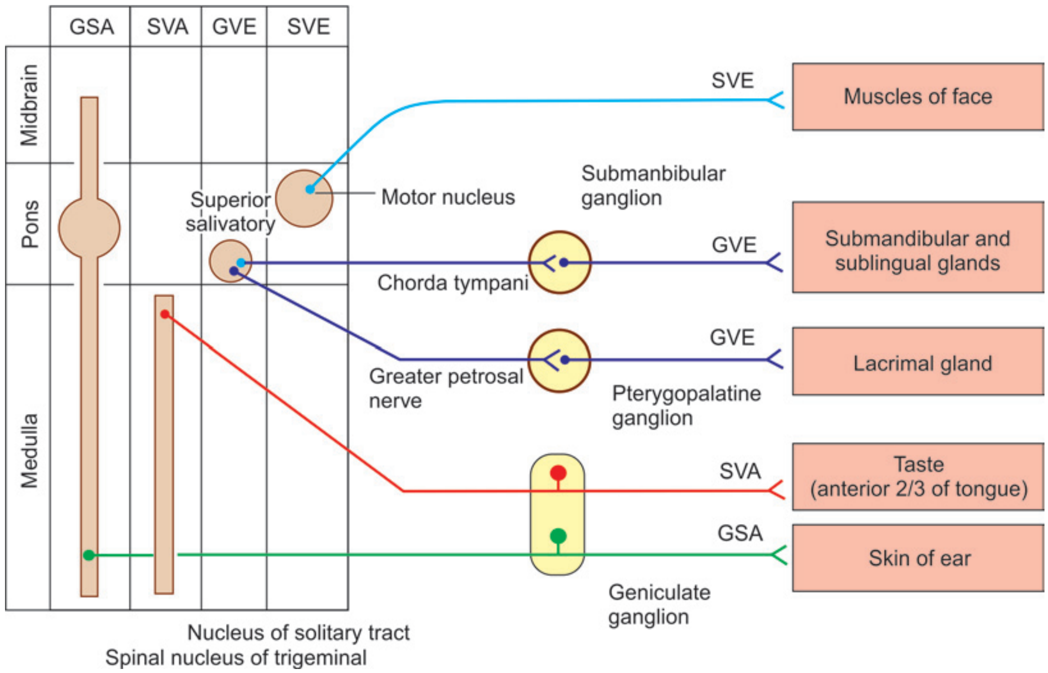

Figure 9.15: Scheme to show the functional components of the facial nerve GSA, general somatic afferent; SVA, special visceral afferent; GVE, general visceral efferent; SVE, special visceral efferent

of the tongue (and some in the soft palate). The central processes of the ganglion cells carry these sensations to the upper part of the nucleus of the solitary tract.

- ***General somatic afferent*** fibres are also peripheral processes of some cells of the geniculate ganglion. They innervate a part of the skin of the external ear. The central processes of these cells end in the spinal nucleus of the trigeminal nerve.

Clinical Correlation

The facial nerve supplies the muscles of the face, including the muscles that close the eyelids and the mouth. The nerve is tested as follows:

- Ask the patient to close his eyes firmly. In complete paralysis of the facial nerve, the patient will not be able to close the eye on the affected side. In partial paralysis, the closure is weak and the examiner can easily open the closed eye with his fingers (which is very difficult in a normal person).

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- Ask the person to smile. In smiling, the normal mouth is more or less symmetrical, the two angles moving upwards and outwards. In facial paralysis, the angle fails to move on the paralyzed side.
- Ask the patient to fill his mouth with air. Press the cheek with your finger and compare the resistance (by the buccinator muscle) on the two sides. The resistance is less on the paralyzed side. On pressing the cheek, air may leak out of the mouth because the muscles closing the mouth are weak.
- Sensations of taste can be tested by applying substances that are salty (salt), sweet (sugar), sour (lemon), or bitter (quinine) to the anterior two thirds of the tongue. The mouth should be rinsed and the tongue dried before the substance is applied.

Paralysis of Facial Nerve

Paralysis of the facial nerve is fairly common. It can occur due to injury or disease of the facial nucleus (**nuclear** paralysis) or of the nerve anywhere along its course

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Table 9.5 | Lower Motor Neuron Lesion of Facial Nerve

S. No	Site of lesion	Effect
1	Stylomastoid foramen	Ipsilateral loss of movement of all facial muscles (Bell's palsy)
2	Geniculate ganglion	As in 1 + Hyperacusis, decreased taste from anterior two-thirds of the tongue, decreased salivary secretion, decreased lacrimation.
3	Internal acoustic meatus	As in 2 + involvement of vestibulocochlear nerve which will result in deafness.
4	Facial nucleus (nuclear paralysis)	As in 2

Table 9.6 | Difference between Supranuclear Lesion and Infranuclear Lesion of Facial Nerve

S.No	Supranuclear lesion of facial nerve	Infranuclear lesion of facial nerve
1	Lesion is usually in internal capsule	Lesion is usually at stylomastoid foramen
2	Accompanied by hemiplegia, on the same side as facial paralysis	Hemiplegia, seen only in nuclear paralysis in lower pons, will be contralateral
3	Movements of the lower part of the face affected because the upper part of the face is under bilateral cortical control	Movements of the entire half of face affected
4	Voluntary movements are affected, emotional expressions appear to be normal since different pathways are involved	Both voluntary and emotional movements are affected since it is final common pathway

(***infranuclear*** paralysis). In the most common type of infranuclear paralysis called Bell's palsy the nerve is affected near the stylomastoid foramen(Table 9.5). Facial muscles can also be paralysed by interruption of corticonuclear fibres running from the motor cortex to the facial nucleus: this is referred to as ***supranuclear*** paralysis (Table 9.6 and Figure 9.16).

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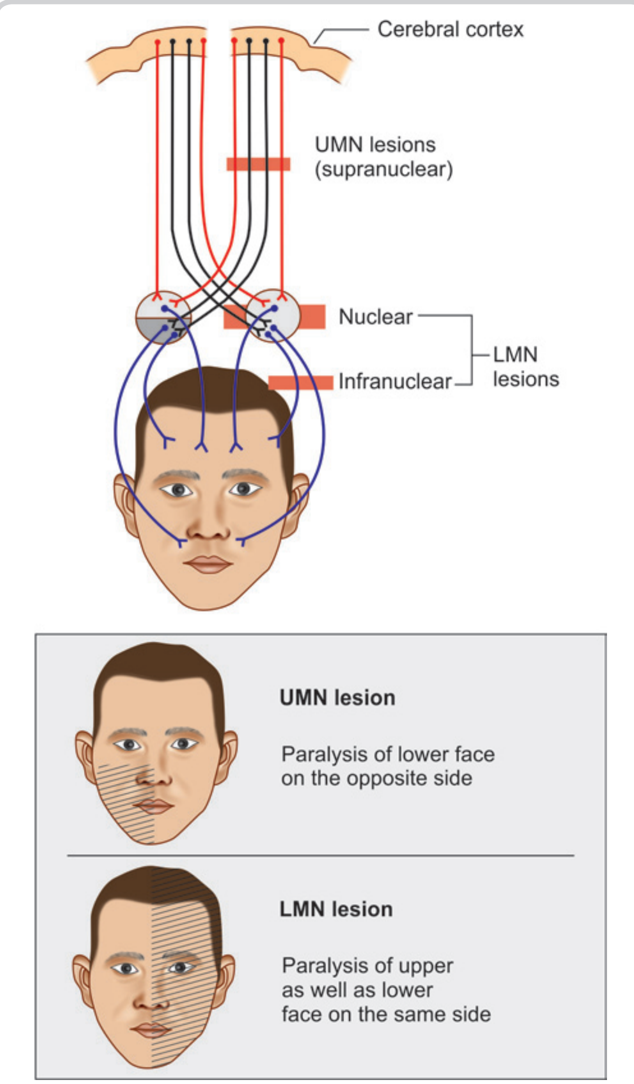

Figure 9.16: Effects of upper motor neuron and lower motor neuron lesions of the facial nerve

The effects of paralysis are due to the failure of the muscles concerned to perform their normal actions. Some effects are as follows:

- The normal face is more or less symmetrical. When the facial nerve is paralysed on one side the most noticeable feature is the loss of symmetry.
- Normal furrows on the forehead are lost because of paralysis of the occipitofrontalis.
- The palpebral fissure is wider on the paralysed side because of paralysis of the orbicularis oculi. The corneal and conjunctival reflexes are lost for the same reason.

The neural pathway for corneal / conjunctival reflex:

Touch of cornea (nacociliary nerve) / conjunctiva (ophthalmic / maxillary) → trigeminal ganglion → main sensory nucleus of trigeminal in pons → motor nucleus of facial → facial nerve → orbicularis oculi

- There is marked asymmetry of the mouth because of paralysis of the orbicularis oris and of muscles inserted into the angle of the mouth. This is most obvious when a smile is attempted. ***When the patient attempts to smile, the angle of the mouth deviates to the normal side***.
- During mastication food tends to accumulate between the cheek and the teeth. (This is normally prevented by the buccinator).

VIII. Vestibulocochlear Nerve

Functional Components

Both the cochlear and vestibular divisions of this nerve are made up of ***special somatic afferent*** fibres. The fibres of the cochlear nerve are central processes of bipolar cells in the spiral ganglion. The peripheral processes of these neurons supply the organ of Corti. The fibres of the vestibular nerve are central processes of bipolar neurons in the vestibular ganglion. The peripheral processes of these neurons innervate the semicircular ducts, the utricle, and the saccule of the internal ear.

In the past, this nerve has also been called the auditory or statoacoustic nerve.

Clinical Correlation

The cochlear part is tested as follows:

- The hearing of the patient can be tested by the ticking of a watch. The distance at which the sounds are first heard should be compared with the other ear.

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- Air conduction and bone conduction can be compared by using a tuning fork. Strike the tuning fork against an object so that it begins to vibrate producing sound. Place the tuning fork near the patient's ear and then immediately put the base of the tuning fork on the mastoid process. Ask the patient where he hears the sound better. This is called ***Rinne's test***. (Air conduction should be better than bone conduction). Bone conduction is better than air conduction in ***conductive*** deafness.
- In another test the base of a vibrating tuning fork is placed on the forehead. The sound should be heard equally in both ears. This is ***Weber's test***. Sound is localized to affected ear in conductive deafness; but to the normal ear in ***sensori-neural*** deafness.

The vestibular part is tested as follows:

Asymmetric function in the vestibular apparatus is diagnosed by ***caloric test*** (***vestibulo-ocular reflex***). Patient is laid supine with the head end tilted above by 30 degrees. This makes the lateral semicircular vertical. Cold and warm water (30 degrees Celsius and 44 degrees Celsius) is introduced alternately into the external auditory canal, usually using a syringe. The temperature difference between the body and the injected water creates a convective current in the endolymph of the lateral semicircular canal. Hot water causes eyes to drift to the opposite side, and cold water causes the eyes to drift to the same side. This results in horizontal nystagmus (oscillatory movement of eyeball) in opposite directions. The duration and direction of nystagmus is recorded in each ear.

IX. Glossopharyngeal Nerve

Functional Components

The components of this nerve are as follows:

- ***Special visceral efferent*** fibres arise in the nucleus ambiguus and supply the stylopharyngeus muscle.
- ***General visceral efferent*** fibres (preganglionic) begin from the inferior salivary nucleus and travel to the otic ganglion. Postganglionic fibres arising in the ganglion supply the parotid gland.
- ***General visceral afferent*** fibres are peripheral processes of neurons in the inferior ganglion of the nerve. They carry general sensations (touch, pain, and temperature) from the pharynx and the posterior part of the tongue to the ganglion. They also carry inputs from the carotid sinus and carotid body. Central processes of the neurons carry these sensations to the nucleus of the solitary tract. Some fibres from the carotid sinus and body reach the paramedian reticular formation of the medulla.
- ***Special visceral afferent*** fibres are also peripheral processes of neurons in the inferior ganglion. They carry sensations of taste from the posterior one-third of the tongue to the ganglion. The central processes carry these sensations to the nucleus of the solitary tract. The important reflexes mediated by glossopharyngeal nerve are shown in Table 9.7.

Table 9.7 | Important Reflexes mediated by Glossopharyngeal Nerve

Reflex	Afferent Limb	Efferent Limb
Gag reflex	Glossopharyngeal nerve	Vagus nerve
Carotid sinus reflex	Glossopharyngeal nerve	Vagus nerve

Clinical Correlation

Testing of this nerve is based on the fact that the nerve carries fibres of taste from the posterior one-third of the tongue and that it provides sensory innervation to the pharynx.

- Sensations of taste can be tested by applying substances that are salty (salt), sweet (sugar), sour (lemon), or bitter (quinine) to the posterior one-third of the tongue. The mouth should be rinsed and the tongue dried before the substance is applied.
- Touching the pharyngeal mucosa causes reflex constriction of pharyngeal muscles. The glosso-pharyngeal nerve provides the afferent part of the pathway for gag reflex.

Lesions of glossopharyngeal nerve

The lesion of the glossopharyngeal nerve is associated with the following:

- Loss of taste and general sensation from the posterior third of tongue
- Loss of gag reflex, due to interruption of the afferent limb
- The neural pathway for gag reflex:
  Touch of posterior wall of oropharynx → glossopharyngeal nerve → inferior glossopharyngeal ganglion nucleus of tractus solitarius → nucleus ambiguus → vago-accessory nerve → constrictors of pharynx
- Loss of carotid sinus reflex due to interruption of the afferent limb
- Loss of general sensations in pharynx, tonsils, and fauces
- Reduced secretion of saliva, as the nerve is secretomotor to parotid gland.

X. Vagus Nerve and Cranial Part of Accessory

Functional Components

The components of this nerve are as follows (Figure 9.17):

- ***Special visceral efferent*** fibres are processes of neurons in the nucleus ambiguus and supply the muscles of the pharynx and larynx.
- ***General visceral efferent*** fibres arise in the dorsal (motor) nucleus of the vagus. These are preganglionic parasympathetic fibres. They are distributed to thoracic and abdominal viscera. The postganglionic neurons concerned are situated in ganglia close to or within the walls of the viscera supplied.

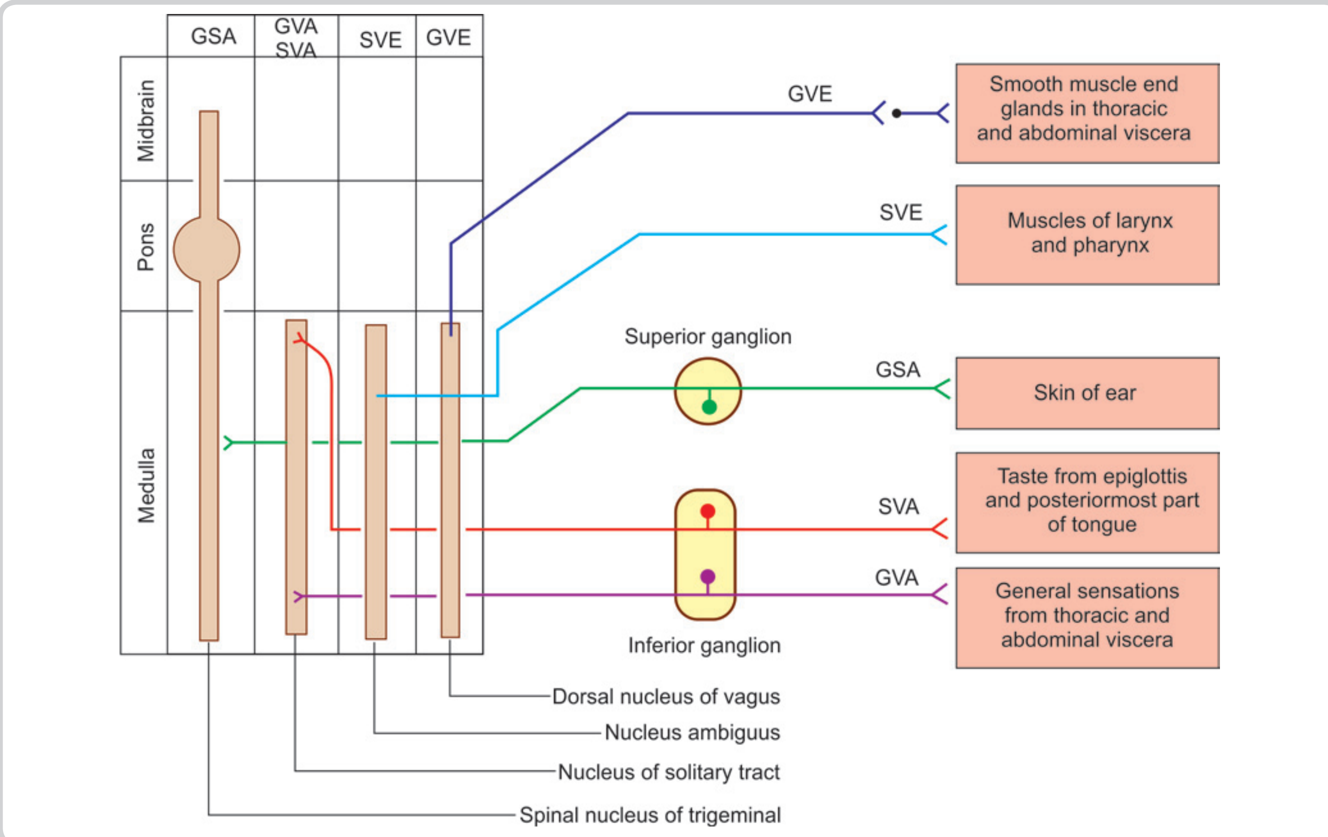

Figure 9.17: Scheme to show the functional components of the vagus nerve GSA, general somatic afferent; GVA, general visceral afferent; SVA, special visceral afferent; SVE, special visceral efferent; GVE, general visceral efferent

- ***General visceral afferent*** fibres are peripheral processes of neurons located in the inferior ganglion of the nerve. They bring sensations from the pharynx, larynx, trachea, oesophagus, and abdominal and thoracic viscera. These are conveyed by central processes of the ganglion cells to the nucleus of the solitary tract. According to some authorities, some of these fibres terminate in the dorsal nucleus of the vagus.
- ***Special visceral afferent*** fibres are also peripheral processes of neurons in the inferior ganglion. They carry sensations of taste from the posteriormost part of the tongue and the epiglottis. The central processes of the neurons concerned terminate in the upper part of the nucleus of the solitary tract.
- ***General somatic afferent*** fibres are peripheral processes of neurons in the superior ganglion and are distributed to the skin of the external ear. The central processes of the ganglion cells terminate in relation to the spinal nucleus of the trigeminal nerve.

Clinical Correlation

This nerve has an extensive distribution, but testing is based on its motor supply to the soft palate and to the larynx.

- Ask the patient to open the mouth wide and say 'aah'. Observe the movement of the soft palate. In a normal person, the soft palate is elevated. When one vagus nerve is paralyzed, the palate is pulled towards the normal side. When the nerve is paralyzed on both sides, the soft palate does not move at all.
- In injury to the superior laryngeal nerve, the voice is weak due to paralysis of the cricothyroid muscle. At first, there is hoarseness, but after some time, the opposite cricothyroid compensates for the deficit and hoarseness disappears.
- Injury to the recurrent laryngeal nerve also leads to hoarseness, but this hoarseness is permanent. On examining the larynx through a laryngoscope, it is seen that on the affected side the vocal fold does not move. It is fixed in a position midway between adduction and abduction. In cases where the recurrent laryngeal nerve is pressed upon by a tumor, it is observed that nerve fibres that supply abductors are lost first (Semon's law).
- In paralysis of both recurrent laryngeal nerves, voice is lost as both vocal folds are immobile (Cadaveric position).
- It may be remembered that the left recurrent laryngeal nerve runs part of its course in the thorax. It can be involved in bronchial or oesophageal carcinoma or by secondary growths in mediastinal lymph nodes.

contd...

XI. Spinal Accessory Nerve

Functional Components

This nerve consists of ***special visceral efferent*** fibres which arise from the lateral part of the anterior grey column of the upper five cervical segments of the spinal cord, to supply the trapezius and sternocleidomastoid muscles.

Clinical Correlation

This nerve is tested as follows:

- Put your hands on the right and left shoulders of the patient and ask him/her to elevate (shrug) his/her shoulders. In paralysis, the movement will be weak on one side (due to paralysis of the trapezius)
- Ask the patient to turn his/her face to the opposite side (against resistance offered by your hand). In paralysis, the movement is weak on the affected side (due to paralysis of the sternocleidomastoid muscle).

Lesion of the spinal accessory nerve

Unilateral peripheral lesion of spinal accessory nerve leads to paralysis of sternocleidomastoid and trapezius muscles.

- Paralysis of sternocleidomastoid leads to *wry neck*, i.e., difficulty in turning of head to the opposite side.
- The paralysis of trapezius results in the inability to shrug the shoulder towards the side of injury. As the lower part of trapezius is also supplied by C3 and C4 segments, an injury to the accessory nerve will not result in complete paralysis of trapezius.

Irritation of the spinal accessory nerve

Results in the condition called 'torticollis'. In this condition, there is a spasmodic contraction of sternocleidomastoid and trapezius.

XII. Hypoglossal Nerve

Functional Components

This nerve is made up of the ***somatic efferent*** fibres which are processes of neurons in the hypoglossal nucleus. They supply the muscles of the tongue (except palatoglossus).

The general somatic afferent fibres carrying proprioceptive impulses from muscles of the eyeball, face and tongue are carried by communicating fibres of trigeminal nerve (ophthalmic nerve from eyeball, cutaneous branches of ophthalmic, maxillary and mandibular nerves from facial muscles, and lingual branch of mandibular nerve from tongue).

Cranial nerve nuclei with their functional components are summarized in Table 9.8.

Table 9.8 | Summary of Cranial Nerve Nuclei with Their Functional Components

Cranial nerve	Somatic efferent	Special visceral efferent	General visceral efferent	General visceral afferent	Special visceral afferent	General somatic afferent	Special somatic afferent
Olfactory					Olfactory epithelium*		Olfactory epithelium*
Optic							Bipolar cells pf retina
Oculomotor	Oculomotor		Edinger-Westphal				
Trochlear	Trochlear						
Trigeminal		Motor				Mesencephalic, main sensory and spinal	
Abducens	Abducent						
Facial		Motor	Superior salivatory		Tractus solitarius	Belonging to trigeminal	
Vestibulo-cochlear							Vestibular and Cochlear
Glosso-pharyngeal		Ambiguus	Inferior salivatory	Tractus solitarius	Tractus solitarius	Belonging to trigeminal	
Vago-accessory		Ambiguus	Dorsal vagal	Tractus solitarius	Tractus solitarius	Belonging to trigeminal	
Spinal accessory		Accessory					
Hypoglossal	Hypoglossal						

* Olfactory mucosa develops from nasal placode (ectodermal in origin), hence it is considered as somatic, developmentally. However, due to the close relationship between the sensations of smell and taste, this nerve is functionally classified as visceral.

Clinical Correlation

This nerve supplies muscles of the tongue. To test the nerve, ask the patient to protrude the tongue. In a normal person the protruded tongue lies in the midline. If the nerve is paralysed, the ***tongue deviates to the paralysed side***. The explanation for this is as follows:

Protrusion of the tongue is produced by the pull of the right and left genioglossus muscles. The origin of the right and left genioglossus muscles lies anteriorly (on the mandible), and the insertion lies posteriorly (on to the postero-lateral part of the tongue). Each muscle draws the posterior part of the tongue forwards and medially. Normally, the medial pull of the two muscles cancels out, but when one muscle is paralysed it is this medial pull of the intact muscle that causes ***the tongue to deviate to the paralysed side***.

Multiple Choice Questions

1. Which one of the following nuclei belongs to the general visceral efferent column
  A. Motor nucleus of facial
  B. Motor nucleus of trigeminal
  C. Dorsal nucleus of vagus
  D. Nucleus ambiguus

2. The cranial nerve that emerges from dorsal surface of brain is
  A. II
  B. IV
  C. VI
  D. VII

3. The axons that supply the ciliaris muscle of the eye are located in the
  A. Oculomotor nucleus
  B. Superior cervical ganglion
  C. Edinger Westphal nucleus
  D. Ciliary ganglion

4. The mesencephalic nucleus of the trigeminal nerve receives
  A. Pain sensations from the scalp
  B. Proprioceptive impulses from the muscles of mastication
  C. Sensations from the cornea
  D. Tactile impulses from the face

5. The nerves belonging to the somatic efferent column supply the muscles developed from
  A. Somites
  B. Intermediate mesoderm
  C. Pharyngeal arches
  D. Somatopleuric mesoderm

6. Which one of the following nuclei belong to the special visceral efferent column
  A. Oculomotor
  B. Trochlear
  C. Abducent
  D. Facial

7. Which one of the following functional components is represented by the accessory nerve
  A. Somatic efferent
  B. Special visceral efferent
  C. General visceral efferent
  D. General somatic afferent

8. The functional component of the taste sensations carried by glossopharyngeal nerve is
  A. General somatic afferent
  B. Special somatic afferent
  C. General visceral efferent
  D. Special visceral afferent

9. The nucleus ambiguus is associated with which one of the following cranial nerves
  A. Facial
  B. Glossopharyngeal
  C. Spinal accessory
  D. Hypoglossal

10. The nucleus that carries the parasympathetic fibres of the facial nerve begins from
  A. Motor nucleus of facial nerve
  B. Inferior salivatory nucleus
  C. Nucleus of tractus solitarius
  D. Superior salivatory nucleus

Answers

1. C **2.** B **3.** D **4.** B **5.** A **6.** D **7.** B **8.** D **9.** B **10.** D

Chapter 10

Pathways of Special Senses

Specific Learning Objectives

At the end of learning, the student shall be able to:
- Describe the olfactory pathway
- Describe the optic pathway
- Correlate the lesions of optic pathway with the visual defects
- Describe the auditory pathway
- Describe the gustatory pathway

The peripheral end organ for smell is the ***olfactory epithelium*** (Figure 10.1) that lines the upper and posterior parts of the nasal cavity. Nerve fibres arising in this mucosa collect to form about twenty bundles that together constitute an ***olfactory nerve.*** The bundles pass through foramina in the cribriform plate of the ethmoid bone to enter the cranial cavity, where they terminate in the ***olfactory bulb*** (Figures 10.2 and 10.3).

OLFACTORY PATHWAY

The fibres of the olfactory nerves are processes of ***olfactory receptor cells,*** lying in the epithelium lining the olfactory mucosa (Figure 10.4). These receptor cells are homologous to sensory neurons located in sensory ganglia. In other words, the first order sensory neurons of the olfactory pathway are located within the olfactory epithelium itself. In the course of evolution, ***all*** neurons have arisen by modification of epithelial cells and their migration, in most cases, into deeper tissues. The olfactory receptor cells retain their position in the epithelium and are, therefore, regarded as primitive.

Each receptor cell consists of a cell body and of two processes, i.e., it is a bipolar cell. The peripheral process (dendrite) reaches the surface of the olfactory epithelium and ends in a small swelling. A number of cilia are attached to this swelling. The central process (axon) enters the submucosa and forms one fibre of the olfactory nerve. The olfactory nerve fibres terminate in the olfactory bulb.

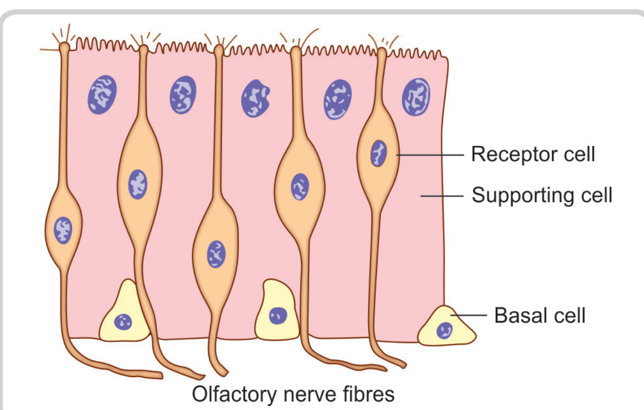

Figure 10.1: Cells to be seen in olfactory epithelium

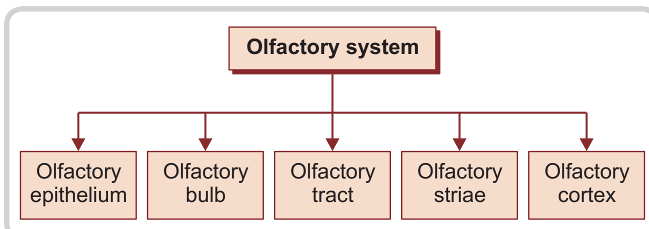

Figure 10.2: Parts of the olfactory system

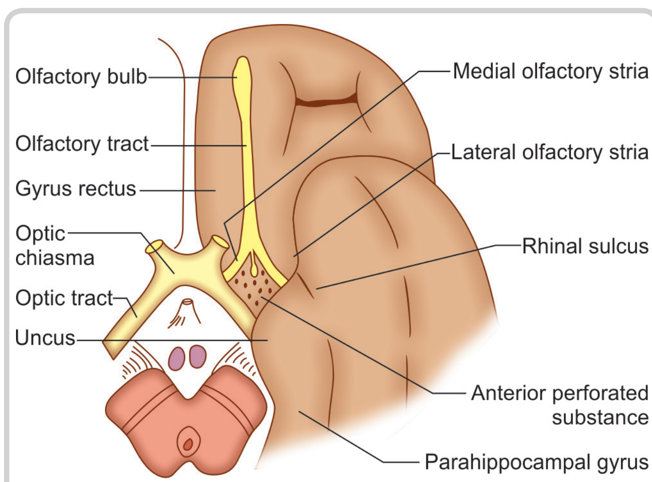

Figure 10.3: Some structures related to the anterior part of the base of the brain

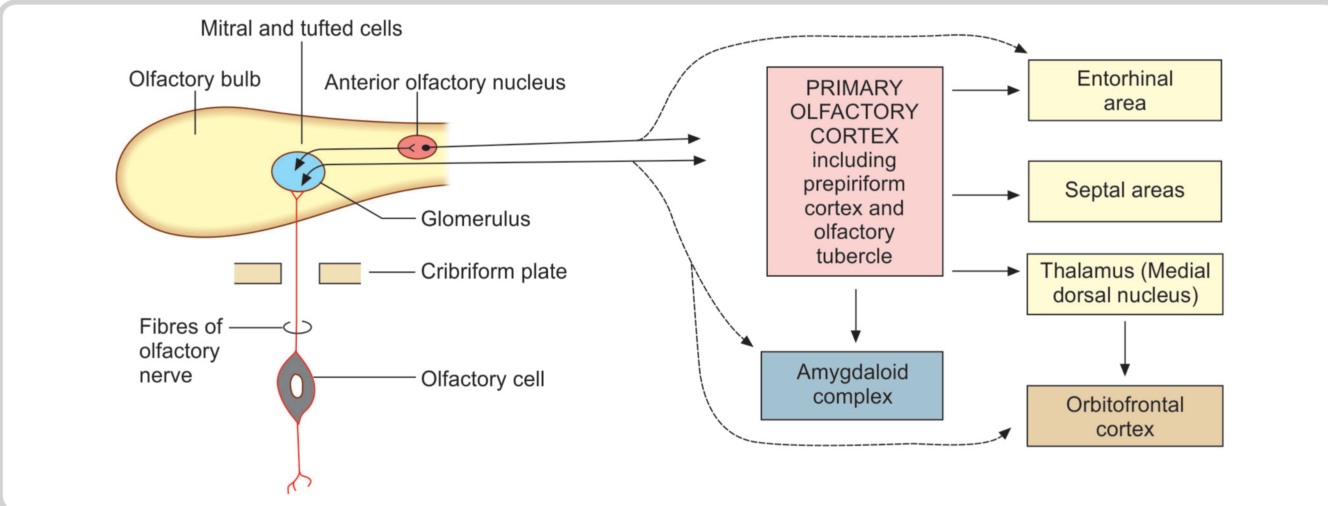

Figure 10.4: Scheme to show the main features of the olfactory pathway

Olfactory Bulb

The olfactory bulb receives fibres of the olfactory nerves, arising from olfactory cells (or olfactory sensory neurons). These incoming fibres synapse with neurons within the bulb. Fibres arising from the latter form the olfactory tract.

Several types of cells are present in the olfactory bulb. The most important of these are:

- The ***mitral cells*** ⎤ give origin to fibres of the
- The ***tufted cells*** ⎦ olfactory tract.
- The ***periglomerular cells*** ⎤ have processes that remain
- The ***granule cells*** ⎦ confined to the bulb.

The olfactory bulb is made up of a number of concentric layers, which are shown in Figure 10.5.

- Incoming fibres of olfactory nerves occupy the most superficial layer
- The second or glomerular layer contains synaptic glomeruli, in which terminals of olfactory nerve fibres synapse with dendrites of mitral cells, tufted cells, and periglomerular cells
- The third layer is in the form of a plexus formed by dendrites of mitral and tufted cells. Somata of tufted cells also lie in this layer
- The fourth layer contains somata of mitral cells
- The fifth layer is made up mainly of axons of mitral and tufted cells
- The sixth layer contains clusters of granule cells.

A small group of nerve cells situated at the transitional zone between the olfactory bulb and olfactory tract constitute the ***anterior olfactory nucleus.***

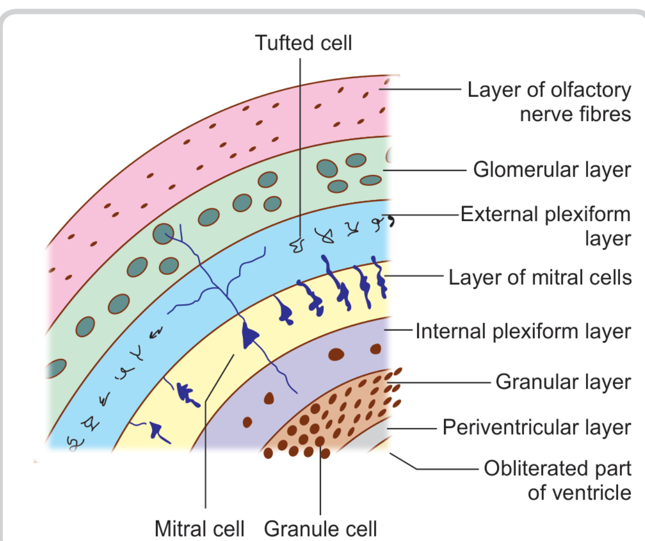

Figure 10.5: Layers of the olfactory bulb

Connections of Olfactory Bulb

The axons of mitral and tufted cells run in the olfactory tract. They also send collateral branches to the neurons of anterior olfactory nucleus. Fibres that originate in the anterior olfactory nucleus pass through the anterior commissure to the opposite olfactory bulb. Fibres from one olfactory bulb also go to the opposite olfactory bulb (Figure 10.6).

The olfactory bulb is continuous posteriorly with the olfactory tract.

Olfactory Tract

The olfactory tract is predominantly made up of axons of mitral and tufted cells of the olfactory bulb.

The olfactory tract also contains centrifugal fibres traveling to the olfactory bulb from various centres in the brain. When traced posteriorly, the olfactory tract divides into ***medial and lateral olfactory striae*** (Figure 10.7)**.**

- When traced backwards, the ***lateral olfactory stria*** reaches the ***limen insulae*** (in the depth of the stem of the lateral sulcus). Here, it bends sharply to the medial side and becomes continuous with a small area of

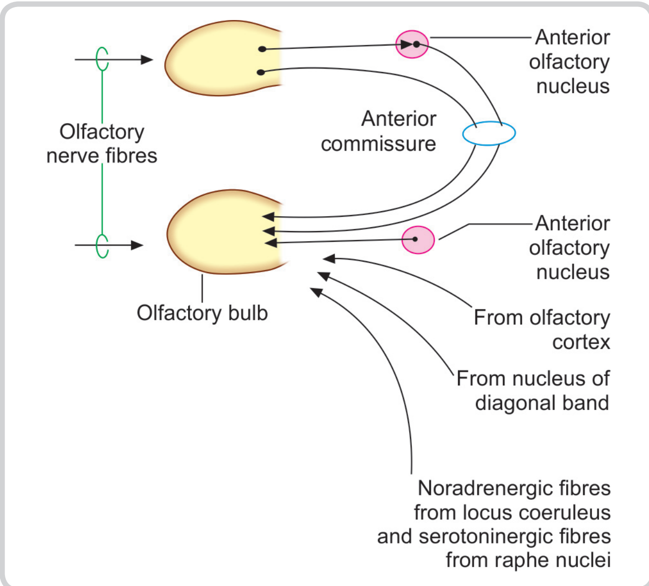

Figure 10.6: Scheme to show the afferents of the olfactory bulb

grey matter lying anterior to the uncus and called the ***gyrus semilunaris*** (or ***periamygdaloid area***). The gyrus semilunaris is closely related to the ***amygdaloid complex,*** which lies deep (i.e., superior) to it. The lateral olfactory stria is covered by a thin layer of grey matter called the ***lateral olfactory gyrus.*** When traced backwards, this gyrus becomes continuous with a part of the cortex called the ***gyrus ambiens.*** The lateral olfactory gyrus and the gyrus ambiens collectively form the ***prepiriform region*** (or area).

The term ***piriform lobe*** is applied collectively to the following parts that have been identified above.

- Prepiriform region (lateral olfactory gyrus and gyrus ambiens)
- Gyrus semilunaris (or periamygdaloid region)
- Lateral olfactory stria
- Anterior part of parahippocampal gyrus, including the uncus (entorhinal area, Brodmann area 28)

- The ***medial olfactory stria***, reaches the medial surface of the hemisphere, where it ends near the paraterminal gyrus (which lies just in front of the lamina terminalis).
- The ***intermediate olfactory stria*** ends in the olfactory tubercle in the anterior perforated substance.

Primary Olfactory Cortex (Figure 10.4)

As discussed, the primary olfactory cortex lies between anterior perforated substance and the uncus. It receives direct afferents from the lateral olfactory stria.

The main regions receiving direct fibres from the olfactory bulb are:

- The prepiriform cortex (including the lateral olfactory gyrus and the gyrus ambiens)
- The gyrus semilunaris (periamygdaloid area).

Some direct fibres also reach the following:

- Anterior olfactory nucleus, which relays them to other regions
- Olfactory tubercle (in the anterior perforated substance).

The term ***piriform cortex or primary olfactory cortex*** is rather loosely applied to these regions, the areas included vary in different accounts.

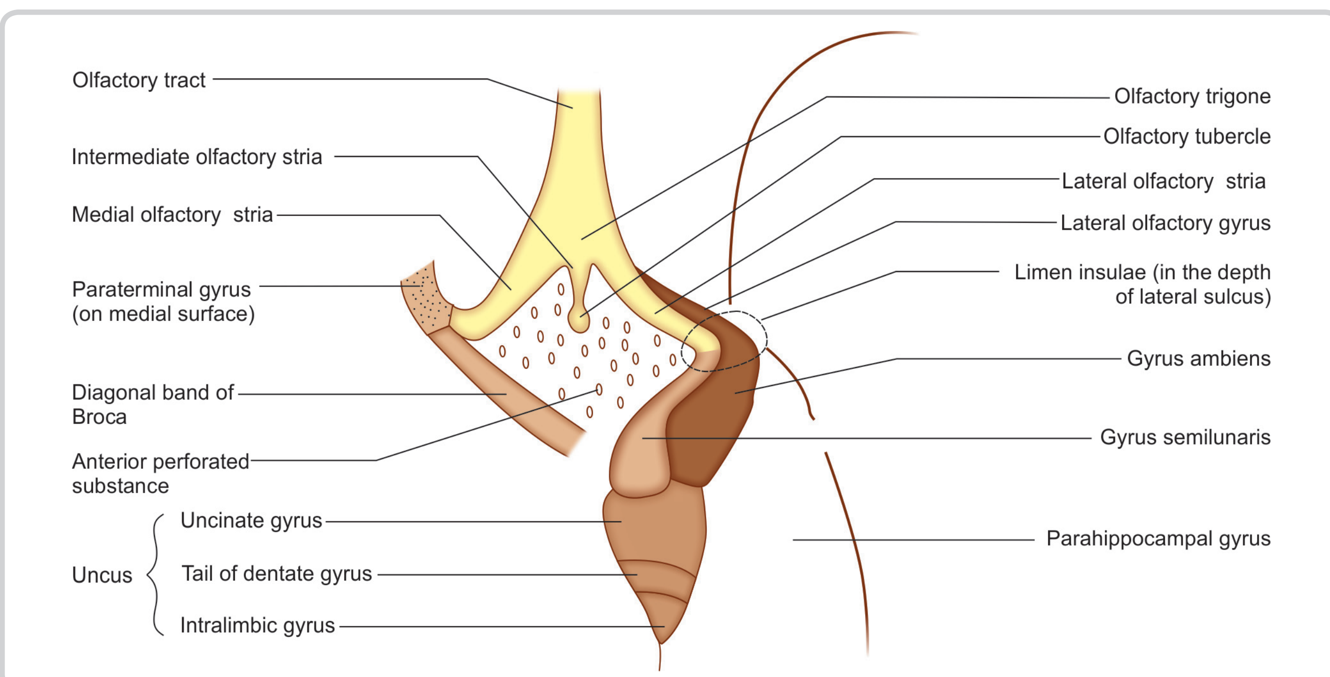

Figure 10.7: Details of olfactory structures present in relation to the anterior perforated substance–Note the subdivisions of the uncus

Note: The fibres of second order sensory neurons reach the primary olfactory cortex directly, without relay in the thalamus, in contrast to all other sensory pathways. However, when the primary olfactory cortex projects to the secondary cortex, information reaches the thalamus.

Secondary Olfactory Cortex

The ***entorhinal area*** comprising of uncus and anterior part of parahippocamal gyrus is often termed secondary olfactory cortex. The ***entorhinal area*** (Brodmann area 28) receives only a few fibres directly, and mainly it receives fibres from primary olfactory cortex. It also receives a direct input from the olfactory cortex through thalamus.

The different parts of olfactory system are shown in Figure 10.2.

VISUAL PATHWAY

The peripheral receptors for light are situated in the ***retina***. Nerve fibres arising in the retina constitute the ***optic nerve***. The right and left optic nerves join to form the ***optic chiasma,*** in which many of their fibres cross to the opposite side. The uncrossed fibres of the optic nerve, along with the fibres that have crossed over from the opposite side, form the ***optic tract***.

The optic tract terminates predominantly in the ***lateral geniculate body***. Fibres arising in this body form the ***geniculocalcarine tract*** or ***optic radiation,*** which ends in the visual areas of the cerebral cortex (Figure 10.8).

The Retina

The retina has a complex structure. It contains photo-receptors that convert the stimulus of light into nervous impulses. These receptors are of two kinds, ***rods*** and ***cones*** (Figure 10.9). There are about seven million cones in each retina. The rods are far more numerous around more than a hundred million.

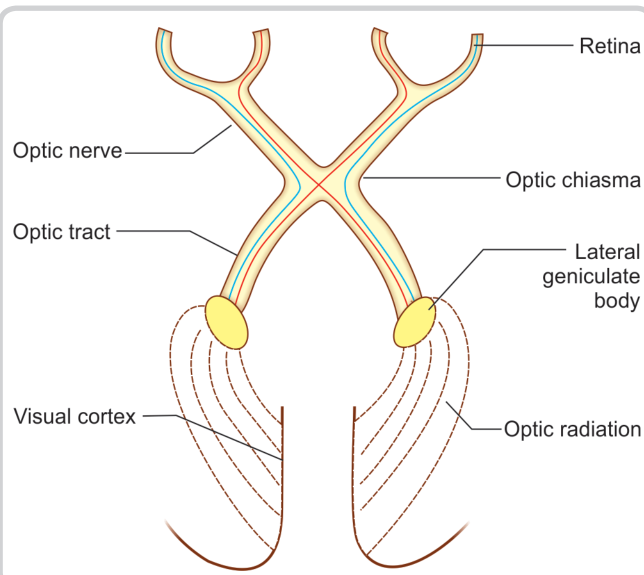

Figure 10.8: The optic pathway–Note that the fibres from the medial (or nasal) half of each retina cross over to the optic tract of the opposite side

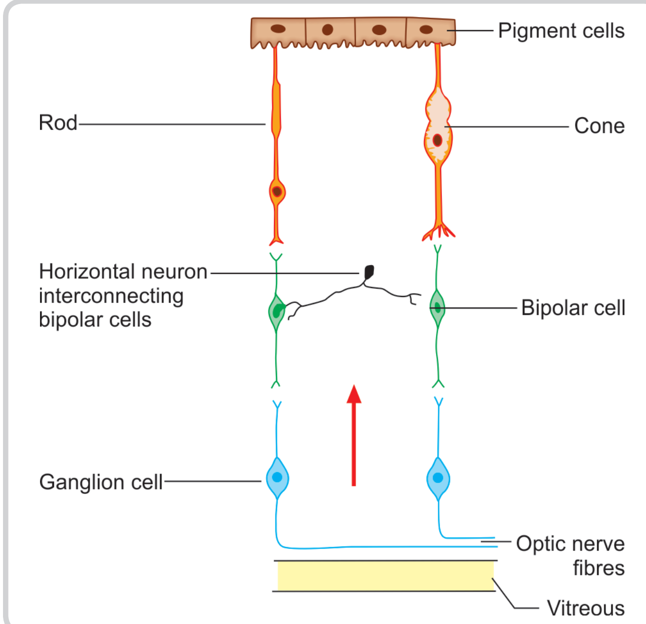

Figure 10.9: Simplified scheme of the neurons within the retina–The red arrow indicates the direction of light falling on the retina

The cones respond best to bright light. They are responsible for sharp vision and for discrimination of colour. They are most numerous in the central region of the retina, which is responsible for sharp vision. This area is about 6 mm in diameter. Within this region, there is a yellowish area called the ***macula lutea***. The centre of the macula shows a small depression called the ***fovea centralis***.

Medial to the central area, there is a circular area called the ***optic disc***. This area is devoid of photoreceptors and is, therefore, called the ***blind spot***. The fibres of the optic nerve leave the eyeball through the region of the optic disc.

The macula lies exactly in the optical axis of the eyeball. When any object is viewed critically, its image is formed on the macula. The fovea centralis contains cones only. Rods, on the other hand, predominate in the peripheral parts of the retina. They respond to poor light and specially to movement across the field of vision.

Each rod or cone are a modified sensory neurons. It consists of a cell body, a peripheral process, and a central process. The cell body contains a nucleus. The peripheral process is rod-shaped, in the case of rods and cone-shaped, in the case of cones (hence, the names rods and cones). The ends of these peripheral processes are separated from one another by processes of pigment cells. The central processes of rods and cones are like those of neurons. They end by synapsing with other neurons within the retina.

The basic neuronal arrangement within the retina is shown in Figure 10.9. The central processes of rods and cones synapse with the peripheral processes of ***bipolar cells***. The central processes of bipolar cells synapse with dendrites of ***ganglion cells***. Axons arising from ganglion cells form the ***fibres of the optic nerve***.

The various elements mentioned above form a series of layers within the retina. The outermost layer (towards the choroid) is formed by the pigments cells, followed in sequence by the rods and cones, the bipolar cells, the ganglion cells, and a layer of optic nerve fibres. The layer of optic nerve fibres is apposed to the vitreous. It is obvious that light has to pass through several of the layers of the retina to reach the rods and cones. This 'inverted' arrangement of the retina is necessary, as passage of light in the reverse direction would be obstructed by the layer of pigment cells.

The pigment cells are important in spacing the rods and cones and providing them with mechanical support. They absorb light and prevent back reflection. A nutritive and phagocytic role has also been attributed to them.

The Visual Field and Retinal Quadrants

When the head and eyes are maintained in a fixed position and one eye is closed, the area seen by that eye constitutes the ***visual field*** for that eye. Now, if the other eye is also opened, the area seen is more or less the same as was seen with one eye. In other words, the visual fields of the two eyes overlap to a very great extent. On either side, however, there is a small area seen only by the eye of that side (Figure 10.10). Although the two eyes view the same area, the relative position of objects within the area appears somewhat dissimilar to the two eyes, as they view the object from slightly different angles. The difference, though slight, is of considerable importance, as it forms the basis for the perception of depth (***stereoscopic vision***).

For the convenience of description, the visual field is divided into right and left halves. It may also be divided into upper and lower halves so that the visual field can be said to consist of four quadrants (Figure 10.11). In a similar manner, each retina can also be divided into quadrants. Images of objects in the field of vision are formed on the retina by the lens of the eyeball. As with any convex lens, the image is inverted. If an object is placed in the ***right*** half of the field of vision, its image is formed on the ***left*** half of the retina and ***vice versa***. The two halves of the retina are usually referred to as ***nasal*** (= medial) and ***temporal*** (= lateral) halves. This introduces a complication as the left half of the left eye is the temporal half, while in the case of the right eye, it is the nasal half. Thus, the image of an object placed in the right half of the field of vision falls on the temporal half of the left retina and on the nasal half of the right retina.

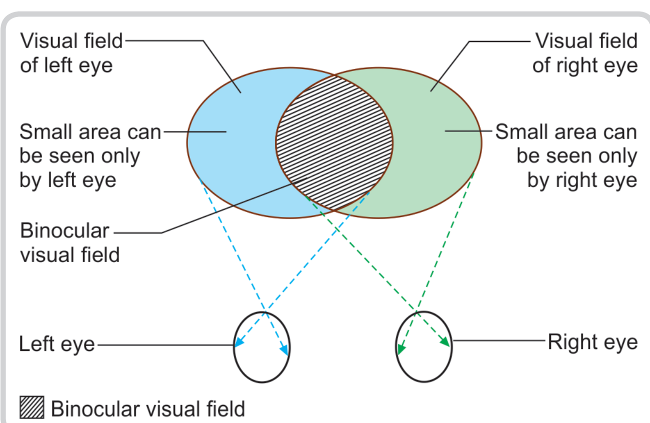

Figure 10.10: The binocular visual field

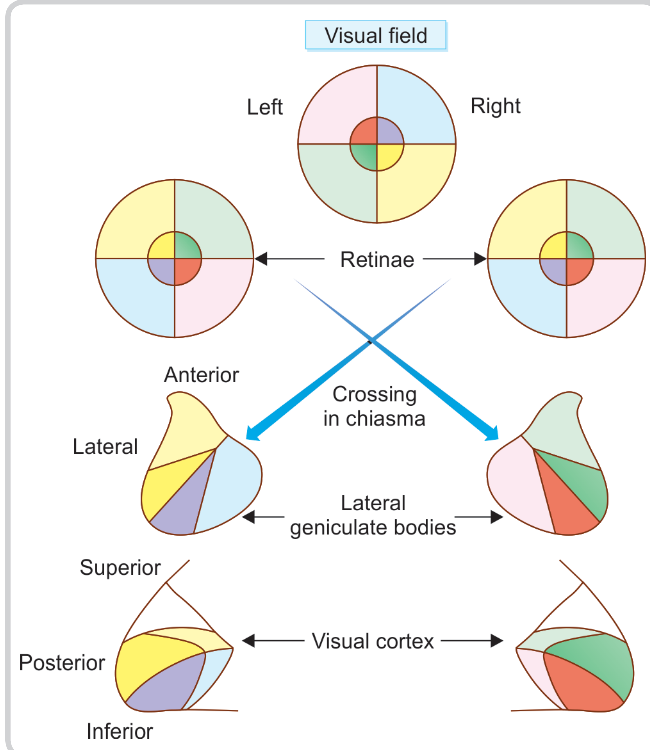

Figure 10.11: Scheme to show the representation of the visual field in the retinae, the lateral geniculate bodies, and the visual cortex of the two sides–the peripheral parts of the visual field are represented by light colours, while the corresponding macular areas are represented by dark colours

Optic Nerve, Optic Chiasma, and Optic Tract

The optic nerve is made up of axons of the ganglion cells of the retina. These axons are at first unmyelinated. The fibres from all parts of the retina converge on the optic disc. In this region, the sclera has numerous small apertures and is, therefore, called the ***lamina cribrosa*** (***crib*** = ***sieve***). Bundles of optic nerve fibres pass through these apertures. Each fibre acquires a myelin sheath as soon as it pierces the sclera. The fibres of the nerve arising from the four

quadrants of the retina maintain the same relative position within the nerve.

The fibres of the optic nerve arising in the nasal half of each retina enter the optic tract of the opposite side after crossing in the chiasma. Fibres from the temporal half of each retina enter the optic tract of the same side (Figure 10.8). Thus, the right optic tract comes to contain fibres from the right halves of both retinae and the left tract from the left halves. In other words, all optic nerve fibres carrying impulses relating to the left half of the field of vision are brought together in the right optic tract and ***vice versa***. Each optic tract carries these fibres to the lateral geniculate body of the corresponding side.

The Lateral Geniculate Body

The grey matter of this body is split into six laminae. Fibres from the eye of the same side end in laminae 2, 3, and 5; while those from the opposite eye end in laminae 1, 4, and 6 (Figure 10.12). The macular fibres end in the central and posterior part of the lateral geniculate body, and this area is relatively large (Figure 10.11). Fibres from the peripheral parts of the retina end in the anterior part of the lateral geniculate body. The upper half of the retina is represented laterally and the lower half of the retina is represented medially. Specific points on the retina project to specific points in the lateral geniculate body. In turn, specific points of this body project to specific points in the visual cortex. In this way, a point-to-point relationship is maintained between the retinae and the visual cortex (retinotopy).

Recent studies of synaptic patterns within the lateral geniculate body indicate that this nucleus is not to be regarded as a simple relay station and that various influences may modify the conduction of impulses through it. In this connection, it may be noted that the lateral geniculate body receives afferents from the visual cortex.

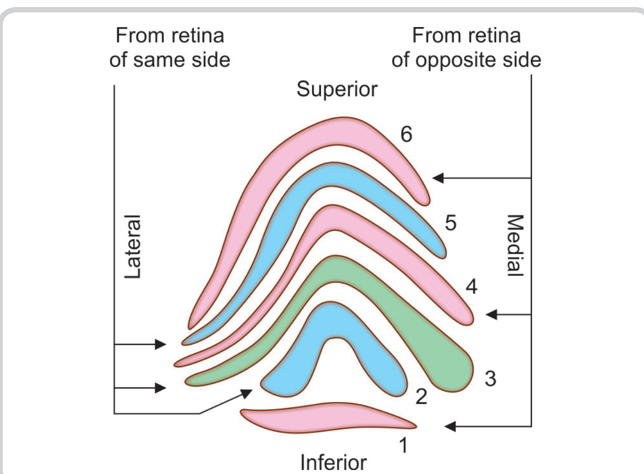

Figure 10.12: Laminae of lateral geniculate body

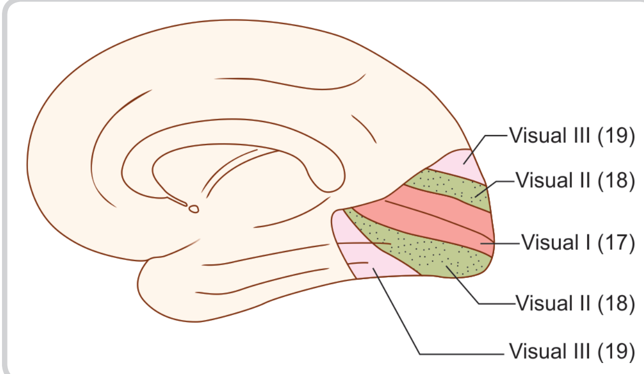

Figure 10.13: Medial aspect of cerebral hemisphere showing visual cortex

Geniculocalcarine Tract and Visual Cortex

Fibres arising from cells of the lateral geniculate body constitute the geniculocalcarine tract or optic radiation. These fibres pass through the retrolentiform part of the internal capsule. The optic radiation ends in the visual areas of the cerebral cortex (areas 17, 18, and 19) (Figure 10.13).

Fibres arising from cells of the lateral geniculate body constitute the geniculocalcarine tract or optic radiation. These fibres pass through the retrolentiform part of the internal capsule to reach the visual area of occipital cortex. Fibres of the optic radiation, from the lower half of the retina (upper field of vision) loop forward and downward into the temporal lobe (to swerve around the atrium and inferior horn of lateral ventricle) before turning backward to the occipital lobe. This is called ***Meyer's loop***.

The optic radiation ends in the visual areas of the cerebral cortex ***(Brodmann's area 17)***. The cortex of each hemisphere receives impulses from the retinal halves of the same side (i.e., from the opposite half of the field of vision). The upper quadrants of the retina are represented above the calcarine sulcus, and the lower quadrants below it. The cortical area for the macula is larger than that for peripheral areas. It occupies the posterior part of the visual area. This area has dual blood supply (posterior cerebral artery and branches of middle cerebral artery). The cortical area for the peripheral part of the retina is situated anterior to the area for the macula.

Neural Pathway for Vision

The first-order sensory neurons carrying visual sensations are bipolar cells of retina. Their dendrites synapse with rods and cones (photoreceptor) and their axons with the dendrites of ganglion cells.

The second-order sensory neurons are the ganglion cells. Axons arising from ganglion cells form the ***fibres of the optic nerve***. The right and the left optic nerves join to form the ***optic chiasma***, where fibres from nasal half

of retina cross to the opposite side and travel through the opposite optic tract to terminate in the opposite lateral geniculate body. The fibres from temporal half of each retina enter the optic tract of the same side to terminate in the ipsilateral geniculate body.

The cell bodies of ***third-order sensory neurons*** are located in the lateral geniculate body. Their axons form the optic radiation, which projects to the visual cortex.

LESIONS OF VISUAL PATHWAY

Injuries to different parts of the visual pathway can produce various kinds of defects. Loss of vision in one half (right or left) of the visual field is called ***hemianopia***. If the same half of the visual field is lost in both eyes the defect is said to be ***homonymous*** and if different halves are lost the defect is said to be ***heteronymous***.

An ***ophthalmoscope*** will show the central artery of retina enter the eye through the optic disc and divides into an upper division and a lower division to supply the upper and lower halves of retina. If one of the divisions gets blocked, e.g. superior division, the perimetry of that eye will show lower ***hemianopia*** (half loss of lower field of vision) with ***a sharp horizontal separation of upper or lower halves***. (This is in complete contrast to hemianopia, with lesions in the posterior parts of visual pathway, where there is sharp vertical separation between left and right halves). (Figure 10.14) ***Glaucoma*** (increased intraocular pressure) compresses the peripheral fibres of optic nerve when they curve and enter the optic disc resulting in ***peripheral loss of field of vision***.

Injury to the optic nerve will obviously produce total blindness in the eye concerned, i.e. ***amblyopia***. Damage to the central part of the optic chiasma (e.g., by pressure from an enlarged hypophysis) interrupts the crossing fibres derived from the nasal halves of the two retinae resulting in ***bitemporal heteronymous hemianopia*** (also called ***tunnel vision***). Complete destruction of the optic tract, the lateral geniculate body, the optic radiation or the visual cortex of one side, results in loss of the opposite half of the field of vision. A lesion on the left side leads to right ***homonymous hemianopia***. A lesion in the lower part of optic radiation called ***Meyer's loop***, (more susceptible due to its longer course and being more superficial in the temporal lobe), results in superior ***quadrantic anopia*** (quarter loss of field of vision). Vascular lesions of visual cortex results in macular sparing, because of the dual vascular supply of macular region by posterior cerebral and middle cerebral arteries. A compressive lesion, e.g. meningioma, glioma, will not produce macular sparing.

AUDITORY PATHWAY

The internal ear contains the organ of hearing called the cochlea. The cochlea has a central bony core called the modiolus, and a spiral canal runs around it. The organ of Corti, which is the sensory epithelium of hearing, sits on the inner surface of the basilar membrane (Figure 10.15).

The ***first order neurons*** of this pathway (***primary auditory pathway***) are located in the ***spiral ganglion***, which consists of two types of cells, type I and type II, present in intimate relationship to the cochlea. These

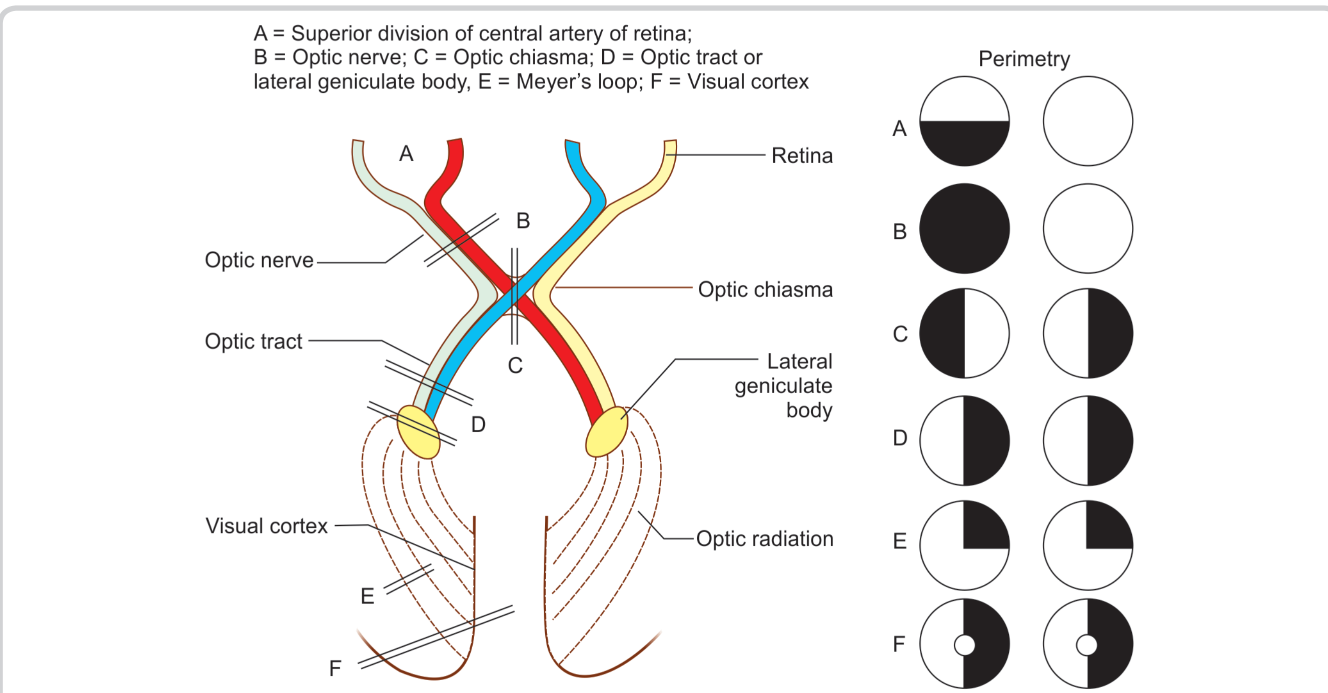

Figure 10.14: Lesions of the visual pathway

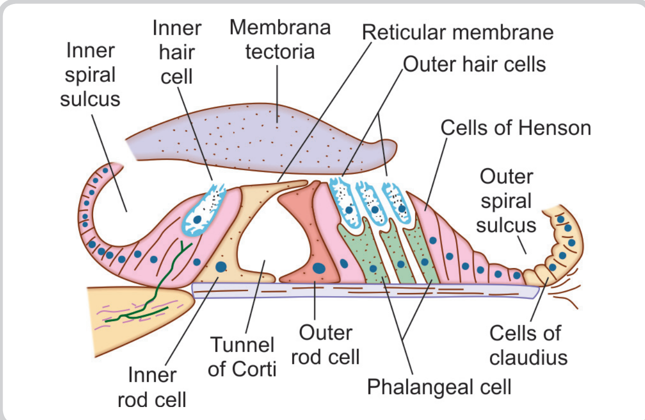

Figure 10.15: Structure of the inner ear

neurons are bipolar (like first order neurons of olfactory and optic nerves, and unlike any other sensory nerves). Their peripheral processes reach the hair cells in the spiral organ of Corti (which is the end organ for hearing). Type I cells innervate inner hair cells. The outer hair cells are innervated by type II cells. The central processes of the neurons form the cochlear nerve, and terminate in the ***dorsal and ventral cochlear nuclei***. The neurons in these nuclei are, therefore, second order neurons. Neurons receiving fibres from different parts of the spiral organ are arranged in a definite sequence in the ventral nucleus (tonotopic arrangement).

The axons of the ***second order neurons (secondary auditory pathway)*** pass medially in the dorsal part of the pons. It has some peculiarities that are as follows:

- Most of them cross to the opposite side, (but ***some remain uncrossed***), and form the lateral lemniscus. The crossing fibres of the two sides form a conspicuous mass of fibres called the ***trapezoid body***.
- The large majority of fibres from the cochlear nuclei terminate in the ***superior olivary complex*** (made up of a number of nuclei). The ***medial superior olivary nucleus*** receives fibres from both cochleae and plays a role in localising the direction of sound (by calculating the time difference in arrival of inputs from the right and left cochleae).
- Some cochlear fibres that do not relay in the superior olivary nucleus join the lateral lemniscus after relaying in scattered groups of cells lying within the trapezoid body. These cells constitute the ***trapezoid nucleus (nucleus of the trapezoid body)***.
- Still other cochlear fibres relay in cells that lie within the lemniscus itself, which form the ***nucleus of the lateral lemniscus***.
- Most of the fibres of the lateral lemniscus ascend to the midbrain and terminate in the ***inferior colliculus***. Fibres arising in the colliculus enter the inferior brachium to reach the medial geniculate body.

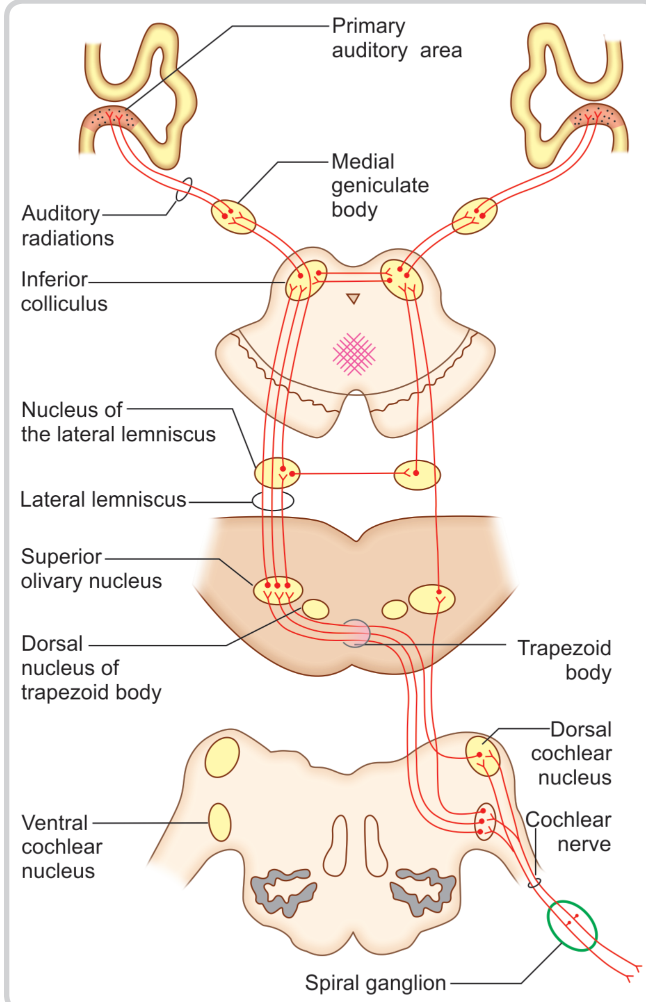

Figure 10.16: The auditory pathway

- Some fibres of the lateral lemniscus reach the ***medial geniculate body*** without relay in the inferior colliculus. (Figure 10.16).

Fibres of the ***third order neurons (tertiary auditory pathway)*** arising in the medial geniculate body form the auditory radiation which ends tonotopically in the auditory area of the cerebral cortex (***anterior and posterior transverse temporal gyri***, Brodmann's areas 41, 42). Since each lateral lemniscus carries impulses arising in the right and left cochlea, lesions of temporal lobe will not cause complete deafness in either ear (Figure 10.17).

GUSTATORY PATHWAY

The gustatory receptors, or taste buds, are microscopic barrel-shaped epithelial chemoreceptors. These receptors are in synaptic contact with the dendrites of gustatory nerves (Figure 10.18).

- ***From the anterior two-thirds of the tongue (excluding the circumvallate papillae):*** Cell bodies of the first order neurons lie in the geniculate ganglion of facial

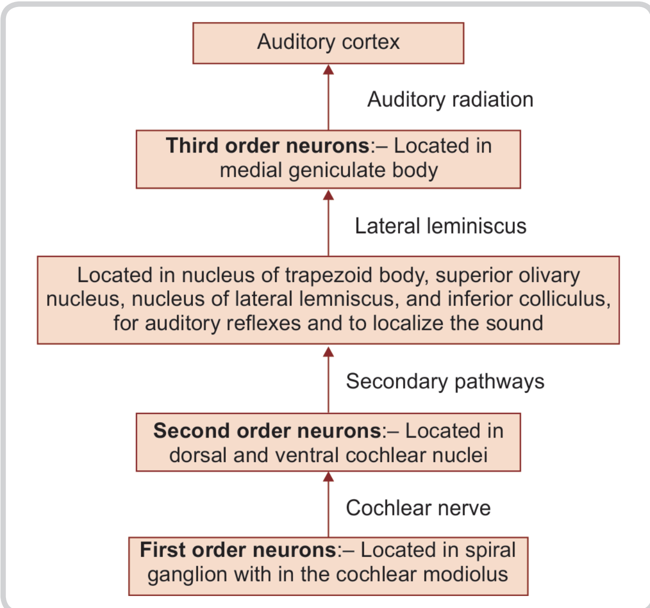

Figure 10.17: Flow diagram showing the neurons involved in auditory pathway

nerve. The peripheral processes (dendrites) pass via the chorda tympani nerve, lingual nerve and anterior two-thirds of the tongue. The central processes end in the upper part of the nucleus of the solitary tract which is sometimes called the **gustatory nucleus (second order neurons)**.

- ***Alternative pathway for taste:*** The peripheral processes (dendrites) of the geniculate ganglion pass via greater petrosal nerve communicating with the lesser petrosal nerve, to reach the otic ganglion, and from there to the lingual nerve. The alternate pathway by-passes the chorda tympani nerve, which passes through the cavity of middle ear and likely to get involved in otitis media.

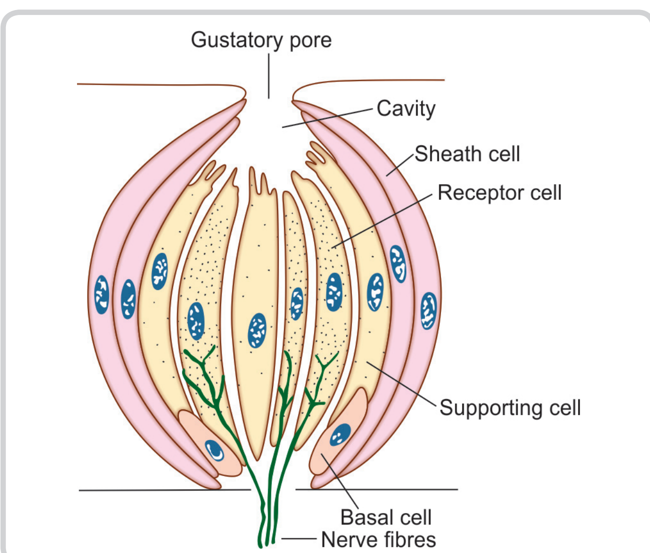

Figure 10.18: Structure of gustatory receptor

- ***From the posterior one-third of the tongue (including the circumvallate papillae):*** Cell bodies of the first order neurons lie in the inferior ganglion of glossopharyngeal nerve. The peripheral processes pass through the terminal branches of glossopharyngeal nerve to the posterior one-third of the tongue. The central processes end in the upper part of the nucleus of the solitary tract.
- ***From the valleculae:*** Cell bodies of the first order neurons lie in the inferior ganglion of vagus nerve. The peripheral processes pass through the internal laryngeal branch of superior laryngeal nerve to the valleculae. The central processes end in the upper part of the nucleus of the solitary tract.
- ***From the soft palate:*** Cell bodies of the first order neurons lie in the geniculate ganglion of facial nerve. The peripheral processes pass via the greater petrosal nerve to the pterygopalatine fossa and from there through the palatine nerves to the soft palate. The central processes end in the upper part of the nucleus of the solitary tract.

Second order gustatory axons start from the ***nucleus of the solitary tract*** and carry visceral impulses to the hypothalamus and the thalamus through the ***solitario-hypothalamic*** and ***solitario-thalamic tracts***, respectively. The fibres going to thalamus cross the midline and terminate in the ventral posteromedial nucleus (along with the trigeminal lemniscus). The nucleus of the solitary tract also sends fibres to the reticular formation, the general visceral efferent cranial nerve nuclei and to the autonomic nuclei (in the intermediolateral grey column) of the spinal cord (Figure 10.19).

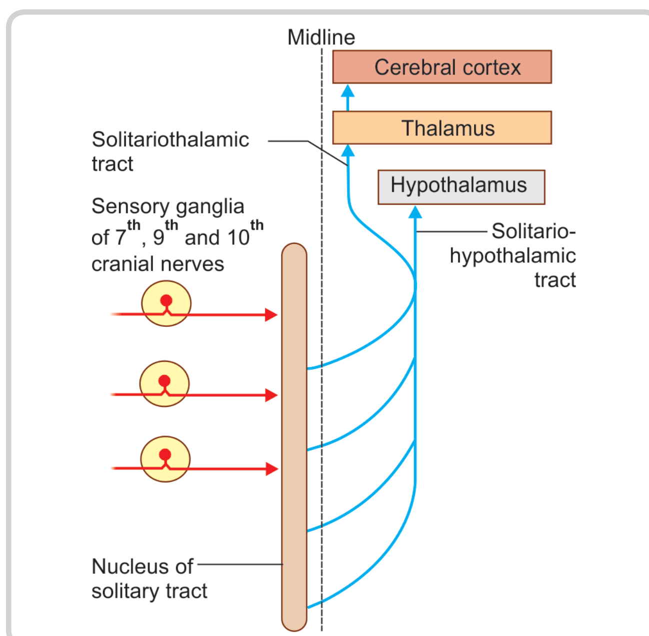

Figure 10.19: Connections of the nucleus of the solitary tract

Tertiary gustatory axons start from the ventral posteromedial nucleus of thalamus and radiate through the posterior limb of internal capsule to the inferior part of the postcentral gyrus of cerebral cortex and the insula. The ascending fibres ending in the hypothalamus, reach the limbic system, which allow autonomic reactions to taste.

Multiple Choice Questions

1. Which one of the following cells forms fibres of olfactory tract?
- A. Bipolar
- B. Granule
- C. Mitral
- D. Periglomerular

2. Where does the medial olfactory stria terminate?
- A. Gyrus semilunaris
- B. Anterior perforated substance
- C. Gyrus ambiens
- D. Paraterminal gyrus

3. Which of the following acts as a reflex and integration centre of the visual system?
- A. Lateral geniculate body
- B. Oculomotor nucleus
- C. Pontine paramedian reticular formation
- D. Superior colliculus

4. Which of the following is the centre for pupillary light reflex?
- A. Lateral geniculate body
- B. Oculomotor nucleus
- C. Pretectal nucleus
- D. Superior colliculus

5. The cells present in retina in its outer nuclear layer are
- A. Amacrine cells
- B. Bipolar cells
- C. Pigment epithelium
- D. Rods and cones

6. Lesion of which part of the optic pathway results in bitemporal hemianopia?
- A. Optic chiasma
- B. Lateral geniculate body
- C. Optic tract
- D. Superior part of optic radiation

7. The primary auditory pathway terminates in
- A. Cochlear nucleus
- B. Inferior colliculus
- C. Superior olivary nucleus
- D. Trapezoid body

8. Auditory radiations commence from
- A. Inferior colliculus
- B. Medial geniculate body
- C. Transverse temporal gyrus
- D. Trapezoid body

9. Dendrites of geniculate ganglia reach the gustatory receptors located in the
- A. Circumvallate papillae
- B. Posterior one-third of tongue
- C. Soft palate
- D. Vallecular region

10. Axons from the inferior vagal ganglion, carrying taste sensations, terminate in
- A. Dorsal nucleus of vagus
- B. Nucleus ambiguus
- C. Nucleus of tractus solitarius
- D. Ventral posteromedial nucleus of thalamus

Answers

1. C **2.** D **3.** D **4.** C **5.** D **6.** A **7.** A **8.** B **9.** C **10.** C

Chapter 11

Cerebellum

Specific Learning Objectives

At the end of learning, the student shall be able to:
- Describe the gross features and subdivisions of cerebellum
- Enumerate the deep nuclei, afferent and efferent connections of cerebellum and the fibres in the cerebellar peduncles
- Describe the morphological subdivisions of cerebellum into archi, paleo and neocerebellum and their functions
- Explain the anatomical basis of clinical features of cerebello-pontine angle tumour and the symptoms of cerebellar disease

INTRODUCTION

The cerebellum (or small brain) lies in the posterior cranial fossa. In an adult, the weight of the cerebellum is about 150 g. This is about 10% of the weight of the cerebral hemispheres. Like the cerebrum, the cerebellum has a superficial layer of grey matter, the cerebellar cortex. Because of the presence of numerous fissures, the cerebellar cortex is much more extensive than the size of this part of the brain would suggest. It has been estimated that the surface area of the cerebellar cortex is about 50% of the area of the cerebral cortex.

The cerebellum lies behind the pons and the medulla. It is separated from the cerebrum by a fold of dura mater called the ***tentorium cerebelli.*** Anteriorly, the fourth ventricle intervenes between the cerebellum (behind), and the pons and medulla (in front, Figure 11.1). Part of the cavity of the ventricle extends into the cerebellum as a transverse cleft. This cleft is bounded cranially by the superior (or anterior) medullary velum, a lamina of white matter (Figure 11.1).

EXTERNAL FEATURES

Parts of Cerebellum

The cerebellum consists of a part lying near the midline called the ***vermis*** and two lateral ***hemispheres.***

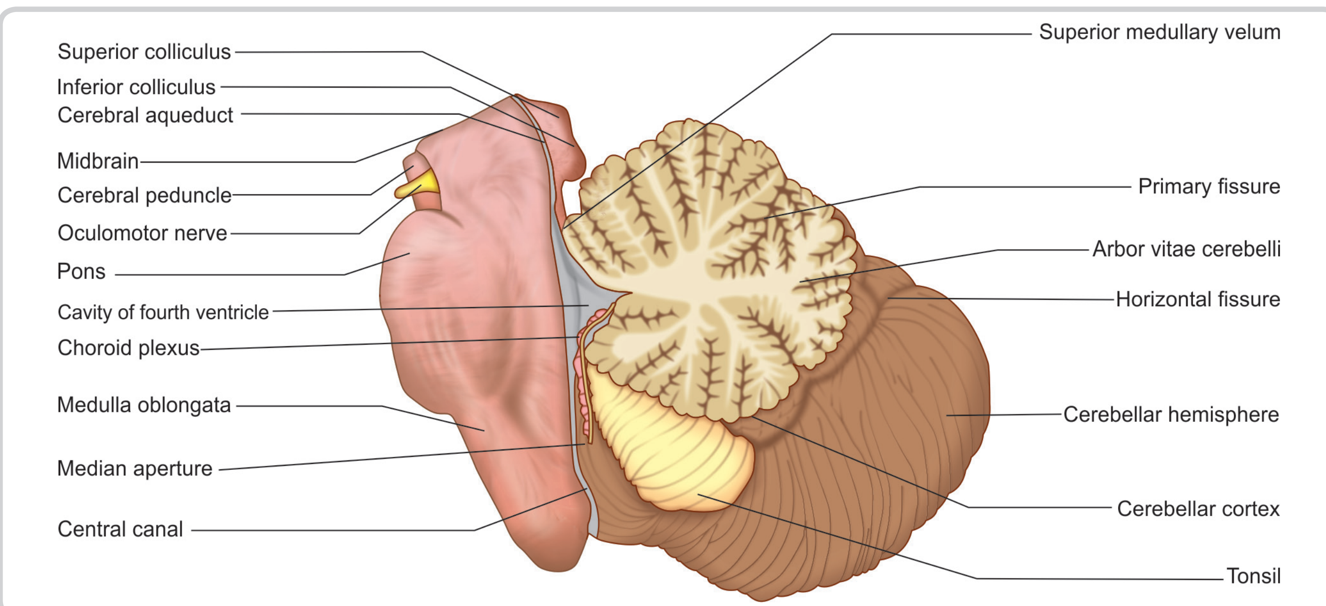

Figure 11.1: Median sagittal section through brainstem and cerebellum

Surfaces of Cerebellum

It has two surfaces, ***superior*** and ***inferior.*** On the superior aspect, there is no line of distinction between the vermis and the hemispheres. On the inferior aspect, the two hemispheres are separated by a deep depression called the ***vallecula.*** The vermis lies in the depth of this depression. On each side, the vermis is separated from the corresponding cerebellar hemisphere by a ***paramedian sulcus***. Anteriorly and posteriorly, the hemispheres extend beyond the vermis and are separated by anterior and posterior ***cerebellar notches.*** The falx cerebelli lies in the posterior notch.

Fissures and Lobes of Cerebellum (Figures 11.2 to 11.4)

The surface of the cerebellum is marked by a series of fissures that run more or less parallel to one another. The fissures subdivide the surface of the cerebellum into narrow leaf-like bands or ***folia***. The long axis of the majority of folia is more or less transverse. Sections of the cerebellum cut at right angles to this axis have a characteristic tree-like appearance to which the term ***arbor-vitae*** (tree of life) is applied (Figure 11.1).

Some of the fissures on the surface of the cerebellum are deeper than others. They divide the cerebellum into ***lobes*** within which smaller ***lobules*** may be recognized (Figure 11.2).

The deepest fissures in the cerebellum are:

- The ***primary fissure*** (***fissura prima***) running transversely across the superior surface
- The ***posterolateral fissure*** seen on the inferior aspect
- The ***horizontal fissure*** (Figures 11.2 and 11.4), which divides the cerebellum into upper and lower halves. The parts seen above the horizontal fissure form the superior surface and those below the fissure form the inferior surface of the cerebellum.

The primary and posterolateral fissures divide the cerebellum into three lobes. The part anterior to the primary fissure is the ***anterior lobe.*** The part between the two fissures is the ***posterior lobe*** (sometimes called the ***middle lobe).*** The posterior lobe extends on both superior and inferior surfaces. The remaining part is the ***flocculonodular lobe,*** present in the inferior surface of the cerebellum. The anterior and posterior lobes together form the ***corpus cerebelli,*** which constitutes the main mass of the cerebellum, the flocculonodular lobe constitutes a very small part of the cerebellum.

The vermis is so called because it resembles a worm. Proceeding from above downwards (Figure 11.2), it consists of the ***lingula, central lobule,*** and ***culmen*** (in the anterior lobe); the ***declive (or simple lobule), folium (or folium vermis), tuber (or tuber vermis), pyramid (or pyramis),*** and ***uvula*** (in the middle lobe); and the ***nodule*** (in the flocculonodular lobe).

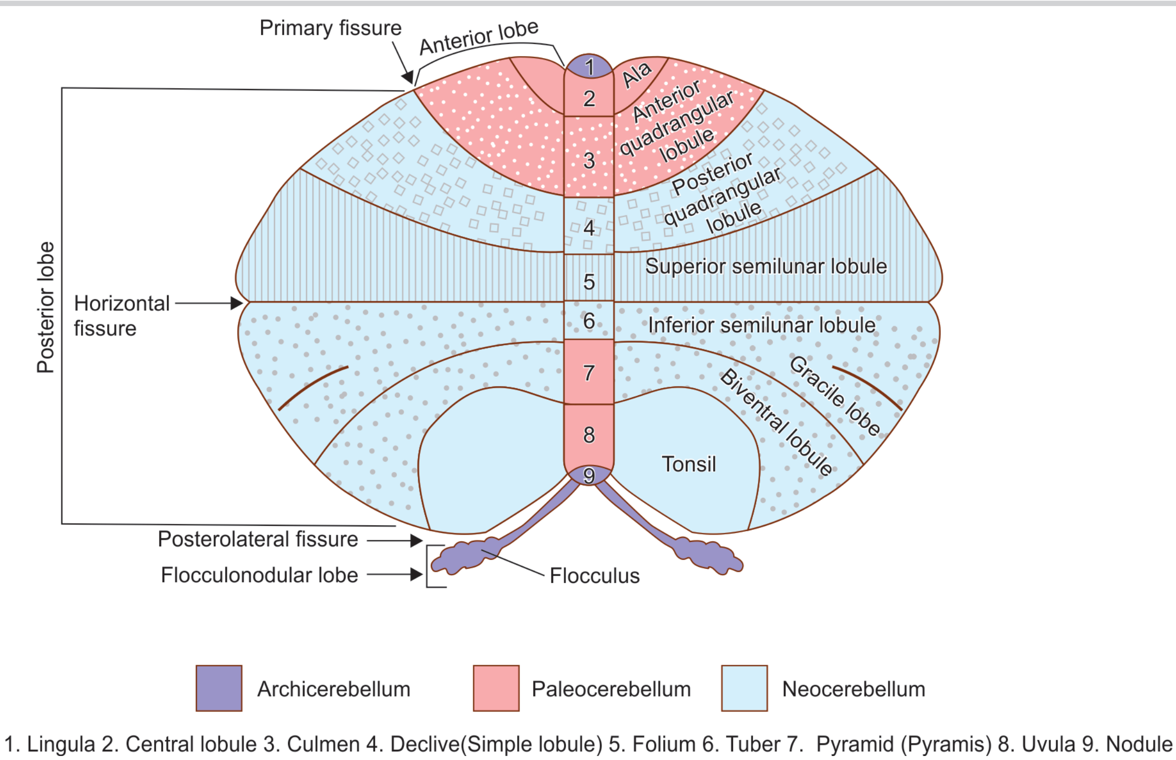

Figure 11.2: Scheme to show the subdivisions of the cerebellum (opened out)

With the exception of the lingula, each subdivision of the vermis is related laterally to a part of the hemisphere. In the anterior lobe, the ***ala*** is lateral to the central lobule and the ***anterior quadrangular lobule*** is lateral to the culmen. In the middle lobe, the ***posterior quadrangular lobule*** lies lateral to the declive, the ***superior semilunar***

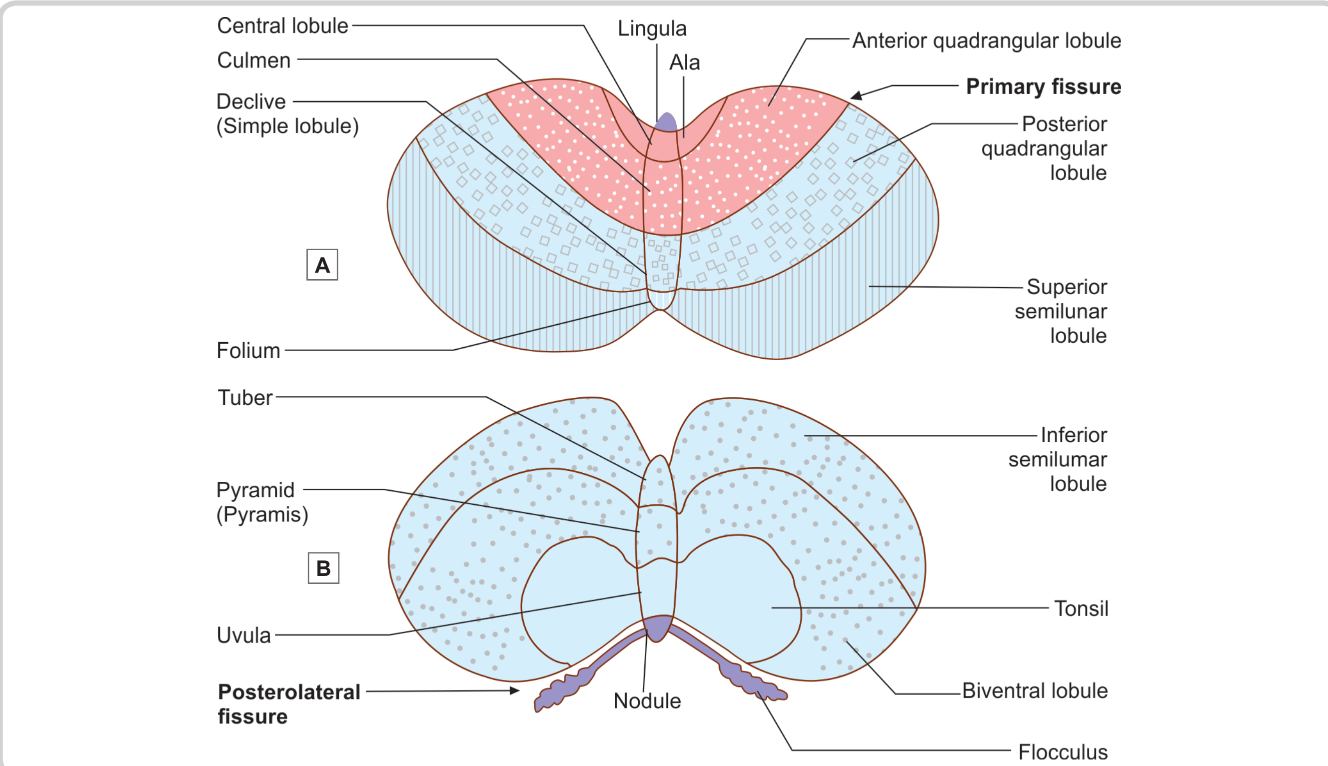

Figure 11.3: Transverse subdivisions of the cerebellum (**A**) As seen on superior aspect (**B**) As seen on inferior aspect

Note: The ***primary fissure*** separates the anterior and posterior lobes. It, therefore, intervenes between the anterior and posterior quadrangular lobules and also separates the culmen and declive. The ***posterolateral fissure*** separates the posterior lobe from the flocculonodular lobe and extends into the interval between the nodule and the uvula.

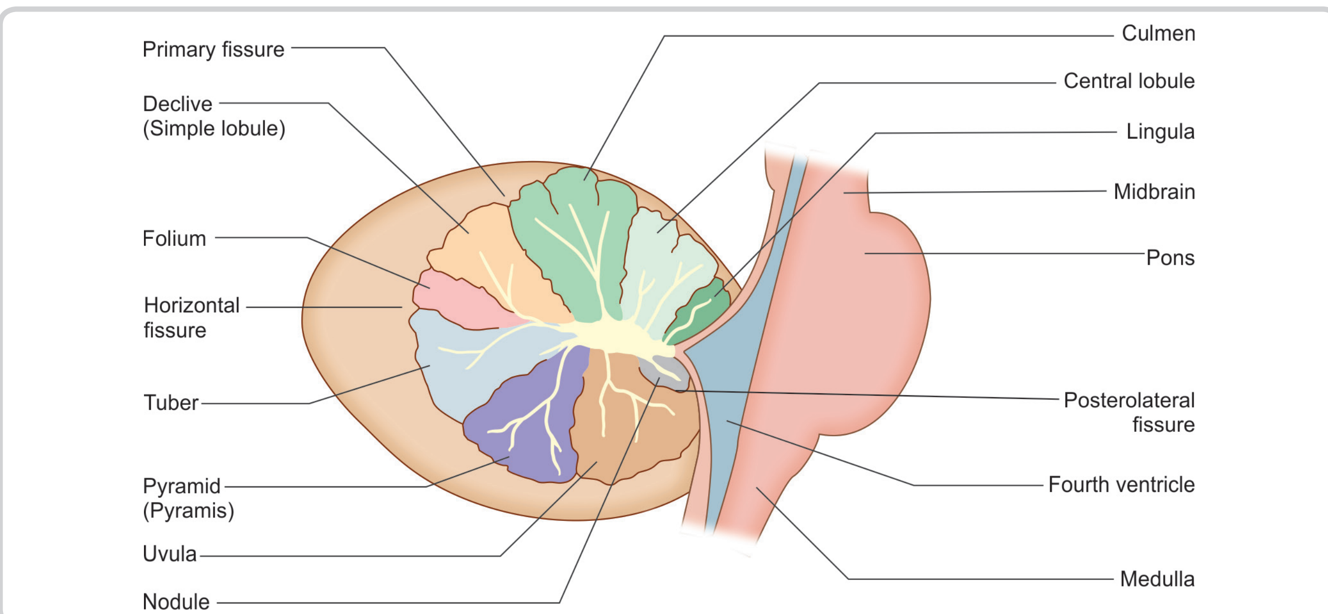

Figure 11.4: Subdivisions of the vermis of the cerebellum as seen in a median section

Note: The position of ***horizontal fissure,*** which divides the cerebellum into upper and lower halves. The parts shown above this fissure are seen on the superior surface of the cerebellum, and those below it on the inferior surface.

Table 11.1 | Morphological Subdivisions of Cerebellum

Lobe	Part of vermis	Part of hemisphere
Anterior	Lingula	—
	Central lobule	Ala
	Culmen	Anterior Quadrangular lobule
Posterior (or middle)	Declive (Simple lobule)	Posterior Quadrangular lobule
	Folium (vermis)	Superior semilunar lobule
	Tuber (vermis)	Inferior semilunar & gracile lobule
	Pyramid (Pyramis)	Biventral lobule
	Uvula	Tonsil
Flocculonodular	Nodule	Flocculus

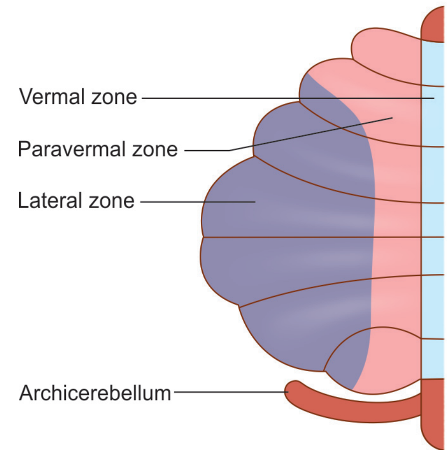

Figure 11.5: Schematic diagram showing functional subdivisions of the cerebellum

lobule is lateral to the folium, the ***inferior semilunar lobule*** and the ***gracile (or paramedian) lobule*** are lateral to the tuber, the ***biventral lobule*** is lateral to the pyramid, and the ***tonsil*** (or ***tonsilla***) lies lateral to the uvula. The nodule is continuous laterally with the flocculus through the inferior medullary velum (Table 11.1).

SUBDIVISIONS OF CEREBELLUM

From developmental, phylogenetic, and functional points of view, the cerebellum is often divided into the following (Figure 11.2 and Table 11.2):

- ***Archicerebellum***: Phylogenetically, it is the oldest part of cerebellum. Anatomically, it consists of flocculonodular lobe and lingula. The connections of the archicerebellum are predominantly vestibular (hence, called vestibulocerebellum), and it is concerned with the maintenance of body equilibrium.
- ***Paleocerebellum***: Phylogenetically, it is the next part of cerebellum to arise and is well developed in reptiles and birds. Anatomically, it consists of anterior lobe (except lingula) and pyramids and uvula of the posterior lobe. The paleocerebellum is connected predominantly to the spinal cord (hence, called spinocerebellum). It is concerned mainly with maintenance of muscle tone and finer control of movements.
- ***Neocerebellum***: It is the most recent part of cerebellum to develop. It is found in mammals only and is largest in humans. Anatomically, it consists of posterior lobe except pyramids and uvula. The neocerebellum has extensive connections with the cerebral cortex (through pontine nuclei, hence called cerebrocerebellum or pontocerebellum). It is usually regarded as being responsible for fine co-ordination of voluntary movements, but its precise role is not known.

From the point of view of its connections, the cerebellar cortex may also be divided into a vermal (vermis), paravermal (or paramedian), and lateral parts—longitudinal parcellation (Figure 11.5).

The cerebellum is made up of a thin surface layer of grey matter, the ***cerebellar cortex*** and a central core of white matter. Embedded within the central core of white matter are masses of grey matter called ***intracerebellar nuclei***.

Table 11.2 | Components, Connections and Functions of the Phylogenetic Subdivisions of Cerebellum

Phylogenetic subdivision	Anatomical component	Chief connections	Functions	Functional Classification
Archicerebellum (oldest part)	Flocculonodular lobe and lingula	Vestibular apparatus	Maintenance of body equilibrium	Vestibulocerebellum
Paleocerebellum	Whole of anterior lobe, (except lingula), pyramid, and uvula	Spinal cord	Maintenance of muscle tone and finer control of movements	Spinocerebellum
Neocerebellum	Whole of posterior lobe, except pyramid and uvula	Pons	Responsible for fine co-ordination of voluntary movements	Cerebrocerebellum

GREY MATTER OF CEREBELLUM

The grey matter of cerebellum is represented by:
- The cerebellar cortex and
- The intracerebellar nuclei.

Structure of Cerebellar Cortex

Most of the grey matter of the cerebellum is arranged as a thin layer covering the central core of white matter. This layer is the ***cerebellar cortex***.

In striking contrast to the cortex of the cerebral hemispheres, the cerebellar cortex has a uniform structure in all parts of the cerebellum. It is divided into three layers as follows (Figure 11.6):
- ***Molecular layer*** (most superficial)
- ***Purkinje cell layer***
- ***Granular layer***, which rests on white matter.

The neurons of the cerebellar cortex are of five main types:
- ***Purkinje cells***, forming the layer named after them
- ***Granule cells***, forming the granular layer
- ***Outer (external) stellate cells*** lying in molecular layer
- ***Basket cells***, lying in the molecular layer
- ***Golgi cells***, present in the granular layer

Intrinsic neurons of cerebellar cortex and their locations are given in Table 11.3.

Table 11.3 | Intrinsic Neurons of Cerebellar Cortex and their Location

Intrinsic neuron	Layer of the cerebellar cortex
Outer (external) stellate cells	Molecular layer
Basket cells	Molecular layer
Purkinje cells	Purkinje cell layer
Granule cells	Granular layer
Golgi cells	Granular layer

Note: All the intrinsic neurons of cerebellar cortex are inhibitory except granule cells.

Molecular Layer

The molecular layer is the superficial layer of the cortex and situated just below the pia matter.

Two types of cells are found in this layer:
- ***Stellate cells:*** Situated in the superficial part of the molecular layer
- ***Basket cells:*** Situated in the deeper layer.

Outer Stellate Cells

These cells and their processes are confined to the molecular layer of the cerebellar cortex. Their dendrites (which are few) synapse with parallel fibres (of granule cells) while their axons synapse with dendrites of Purkinje cells (near their origin).

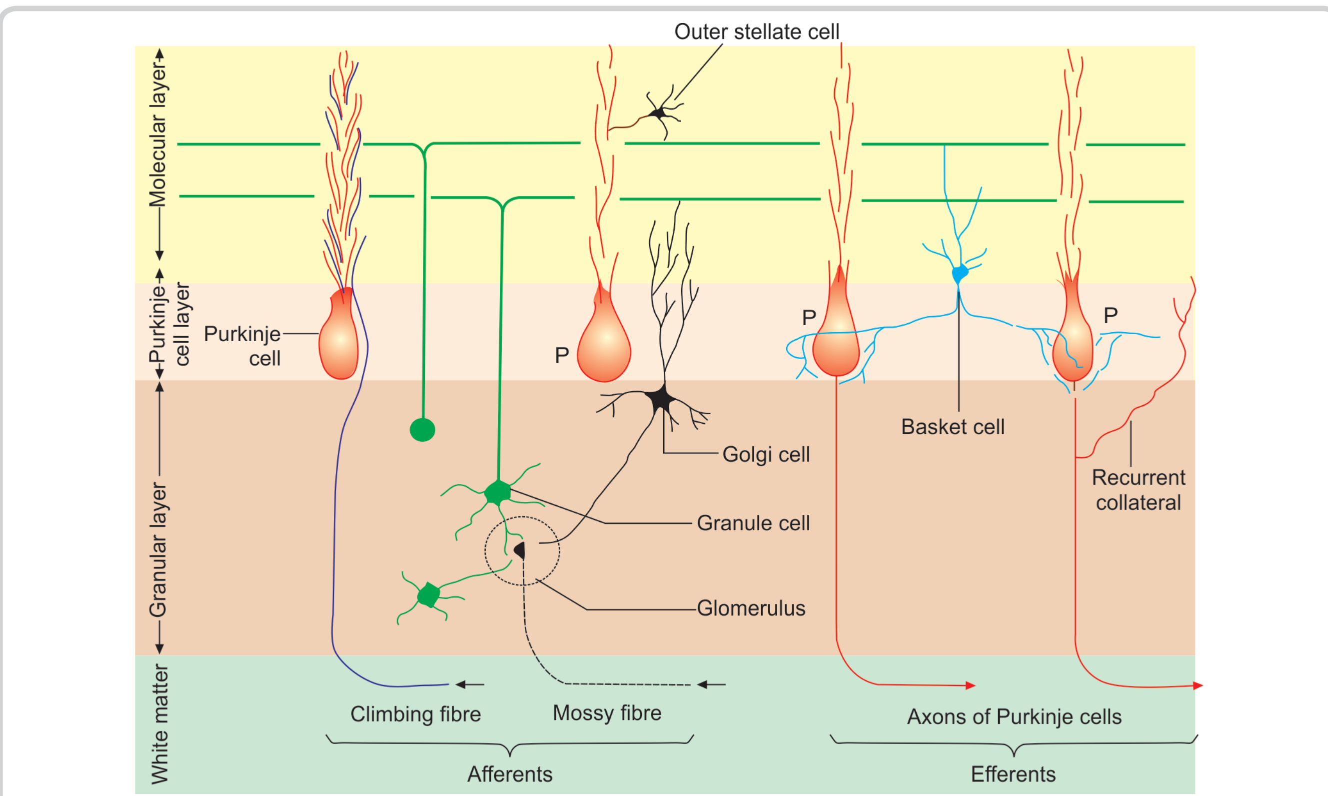

Figure 11.6: Scheme to show the arrangement of neurons in cerebellar cortex

Basket Cells

These cell lie in the deeper part of the molecular layer of the cerebellar cortex. Their dendrites (which are few) ramify in the molecular layer and are intersected by parallel fibres with which they synapse. They also receive recurrent collaterals from Purkinje cells, climbing fibres, and mossy fibres. The axons of these cells branch and form networks (or baskets) around the cell bodies of Purkinje cells. Their terminations synapse with Purkinje cells at the junction of the cell body and axon (preaxon). Each basket cell may synapse with about 70 Purkinje neurons. Basket cells and stellate cells are GABAergic. They are inhibitory to Purkinje cells.

Purkinje Cell Layer

The Purkinje cell layer contains flask-shaped cell bodies of Purkinje cells. This layer is unusual in that it contains only one layer of neurons. The Purkinje cells are evenly spaced. A dendrite arises from the 'neck' of the 'flask' and passes 'upwards' into the molecular layer. Here, it divides and subdivides to form an elaborate dendritic tree. The branches of this 'tree' all lie in one plane (like the fins of a fan or like a vine branching against a wall, Figure 11.7). This plane is transverse to the long axis of the folium. As a result of this arrangement, the dendritic trees of adjoining Purkinje cells lie in planes more or less parallel to one another.

The axon of each Purkinje cell passes 'downwards' through the granular layer to enter the white matter. As described later, these axons constitute the only efferents of the cerebellar cortex. They end predominantly by synapsing with neurons in cerebellar nuclei. They are inhibitory to these neurons.

Granular Layer

It is the innermost layer and consists of numerous granule cells and a few golgi cells, brush cells and synaptic glomeruli.

Granule Cells

These are very small, numerous, spherical neurons that occupy the greater part of the granular layer. The spaces not occupied by them are called ***cerebellar islands***. These islands are occupied by special synaptic structures called ***glomeruli***.

Each granule cell gives off three to five short dendrites. These end in claw-like endings, which enter the glomeruli where they synapse with the terminals of mossy fibres (see below). The axon of each granule cell enters the molecular layer. Here, it divides into two subdivisions each of which is at right angles to the parent axon (forming a T-junction). These axonal branches of granule cells are called ***parallel fibres***. The granule cells being extremely numerous, the parallel fibres are also abundant and almost fill the molecular layer. The parallel fibres run at right angles to the planes of the dendritic trees of Purkinje cells. As a result each parallel fibre comes into contact and synapses with the dendrites of numerous Purkinje cells. Parallel fibres also synapse with Golgi cells, basket cells, and stellate cells.

Golgi Neurons

These are large, stellate cells lying in the granular layer (Figures 11.6 and 11.8), just deep to the Purkinje cells. They are GABAergic inhibitory neurons. Their dendrites enter the molecular layer, where they branch profusely, and synapse

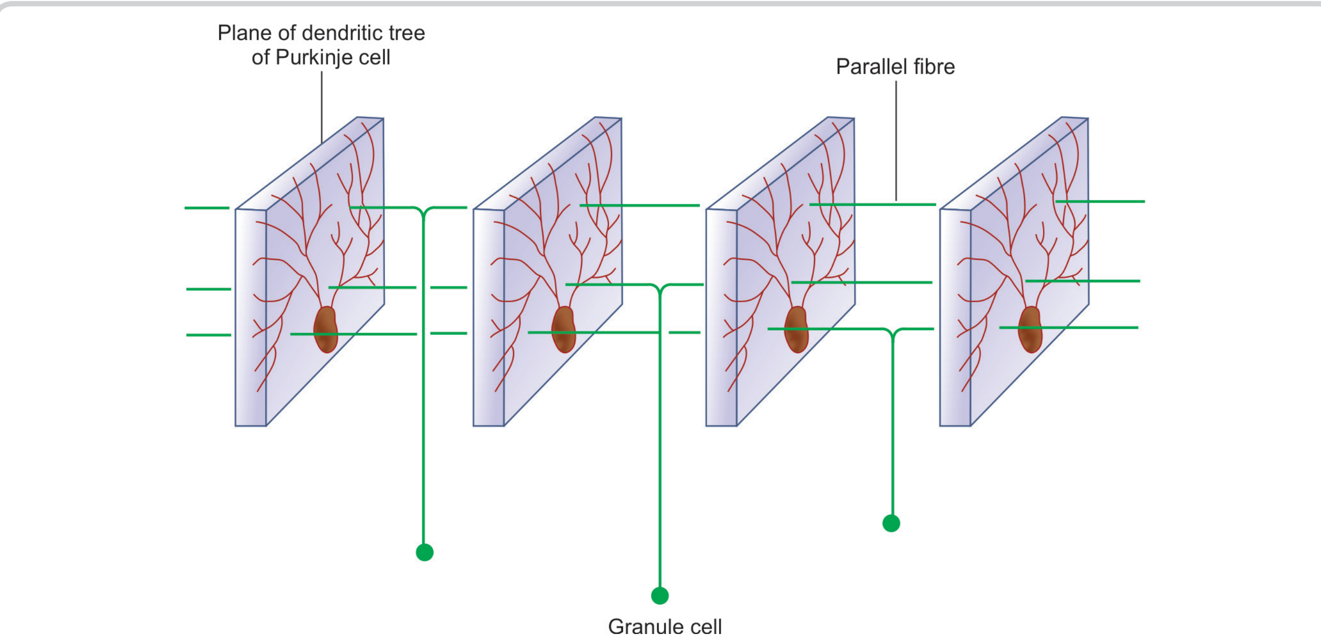

Figure 11.7: Scheme to show the fact that dendritic trees of adjoining Purkinje cells lie in planes that are parallel to one another–Note that the axons of granule cells divide at right angles to form parallel fibres that establish synapses with dendrites of several Purkinje cells

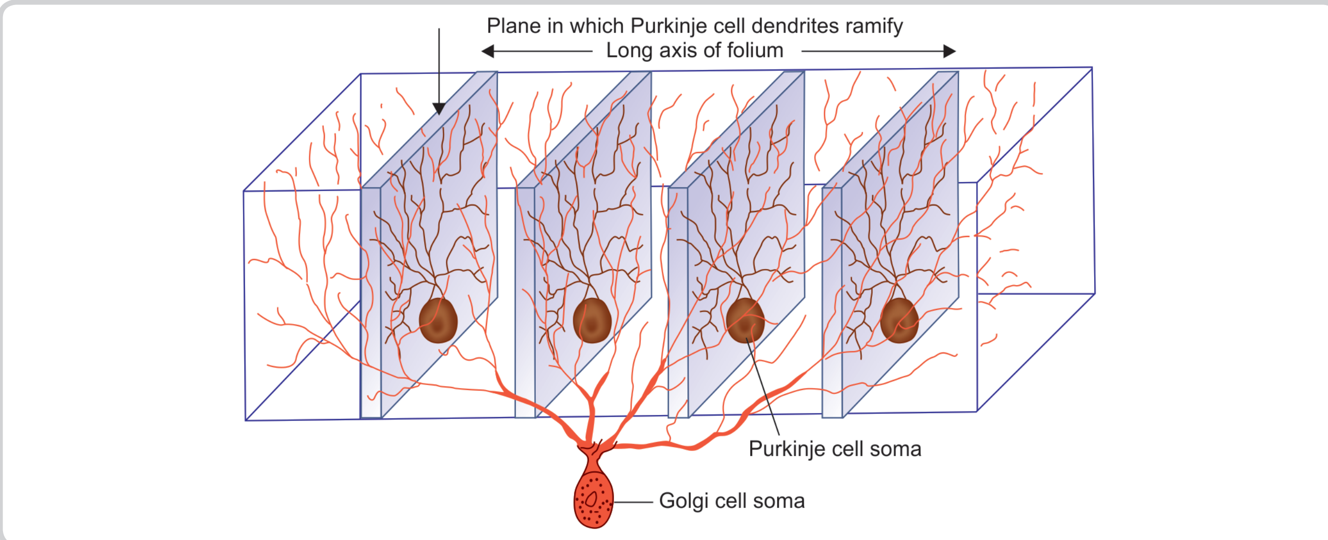

Figure 11.8: Diagram showing relationship of dendrites of one Golgi neuron to those of Purkinje cells

with the parallel fibres. Some dendrites ramify in the granular layer. The axons of these neurons also branch profusely. These branches permeate the whole thickness of the granular layer. They take part in the formation of '***glomeruli'***. Some dendritic branches also reach the glomeruli.

Each Golgi neuron occupies a definite area there being no overlap between the territories of neighboring Golgi cells. It is interesting to note that the territory of each Golgi cell corresponds to that of about ten Purkinje cells.

The Golgi cells are inhibitory neurons and are responsible for feedback inhibition of granule cells.

Structure of Glomeruli

The glomeruli are complex synaptic structures. The core of each glomerulus is formed by the expanded termination of a mossy fibre (Figure 11.9). This termination is called a ***rosette***. Numerous (upto 20) dendrites of granule cells synapse with the rosette. These synapses are axodendritic and excitatory.

The glomerulus also receives axon terminals of Golgi cells. These also synapse with granule cell dendrites. These synapses are inhibitory. Occasionally, a Golgi cell dendrite may enter a glomerulus and synapse directly with the rosette. The entire glomerulus, which is about 10 μm in diameter, is surrounded by a neuroglial capsule.

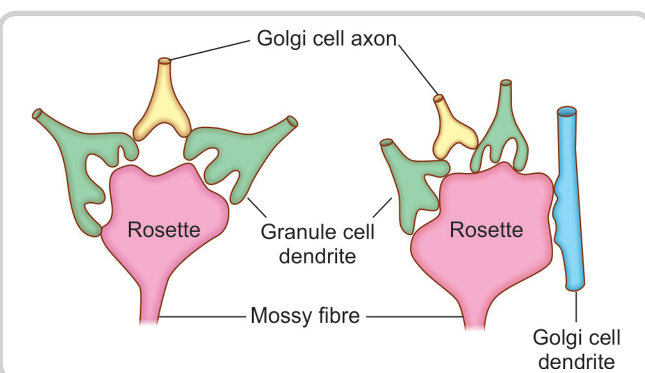

Figure 11.9: Structure of cerebellar glomeruli
(The outer capsule is not shown)

Intracerebellar Nuclei

Embedded in the central core of white matter there are masses of grey matter which constitute the ***cerebellar nuclei.*** From lateral to medial these are as follows (Figure 11.10):

- The ***dentate*** nucleus lies in the centre of each cerebellar hemisphere. Cross section through the nucleus shows a thin lamina of grey matter that is folded upon itself, so that it resembles a crumpled purse with the hilum directed medially.
- The ***emboliform*** (posterior interpositus) and the ***globose*** (anterior interpositus) nucleus are together called as ***nucleus interpositus.*** They lie on the medial side of the dentate nucleus.
- The ***fastigial*** nucleus lies close to the midline in the anterior part of the superior vermis.

These nuclei are close to the roof of IV ventricle and hence are also called as "Roof nuclei".

The regions of cerebellar cortex from which efferent projections pass to the cerebellar nuclei are arranged in a medio-lateral sequence corresponding to the position of the nuclei. The fastigial nucleus receives fibres from the vermis, the globose and emboliform nuclei from paravermal regions, and the dentate nucleus from the lateral region.

WHITE MATTER OF CEREBELLUM

The central core of each cerebellar hemisphere is formed by the white matter. The peduncles are continued into

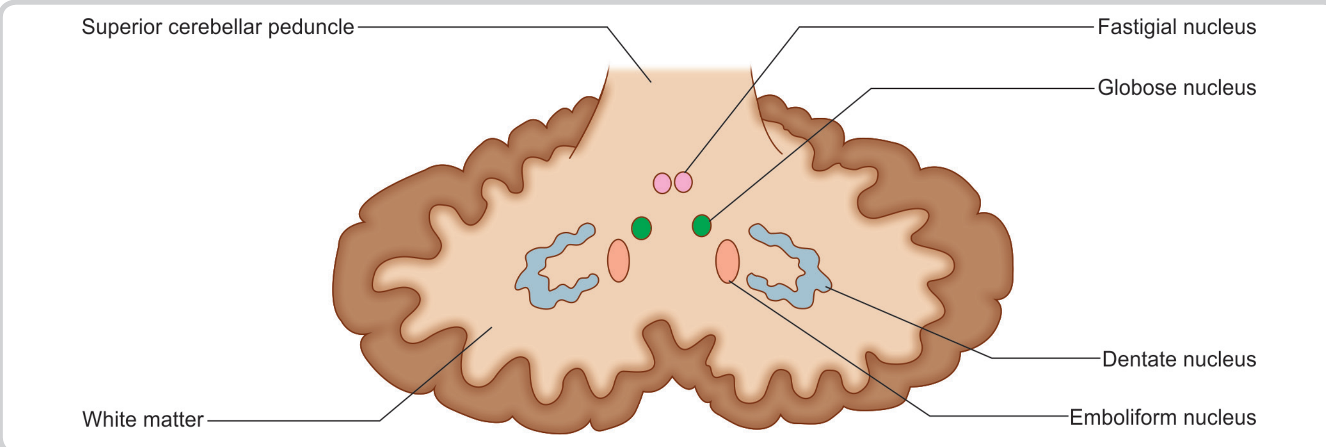

Figure 11.10: Scheme to show the cerebellar nuclei

this white matter. The white matter of the two sides is connected by a thin lamina of fibres that are closely related to the fourth ventricle. The upper part of this lamina forms the superior medullary velum, and its lower part forms two crescentic sheets called inferior medullary vela. Both these take part in the formation of the roof of the fourth ventricle.

The white matter consists of two types of fibres—***intrinsic*** and ***extrinsic***.

- ***Intrinsic fibres:*** Intrinsic fibres remain confined within the cerebellum. They connect different regions of the cerebellum either in the same hemisphere or of the two cerebellar hemispheres.
  - Projection fibres connect cerebellar cortex to the cerebellar nuclei.
  - Association fibres interconnect different parts of the cerebellar cortex.
  - Commissural fibres connect the two cerebellar hemispheres.
- ***Extrinsic fibres:*** Extrinsic fibres connect the cerebellum with other parts of the central nervous system, i.e. brain and spinal cord through afferent and efferent fibres. The fibres entering or leaving the cerebellum pass through three thick bundles called the cerebellar peduncles: superior, middle, and inferior.

Afferent Fibres Entering the Cerebellar Cortex

The afferent fibres to the cerebellar cortex are of two different types:

- Mossy fibres
- Climbing fibres

Mossy Fibres

All fibres entering the cerebellum, other than olivo-cerebellar, end as mossy fibres. Mossy fibres originate from the vestibular nuclei (vestibulocerebellar), pontine nuclei (pontocerebellar), and spinal cord (spinocerebellar) and terminate in the granular layer of the cortex within the glomeruli. Before terminating, they branch profusely within the granular layer, each branch ends in an expanded terminal called a ***rosette*** (Figure 11.9).

Afferent inputs through mossy fibres pass through granule cells to reach the Purkinje cells.

Climbing Fibres

These fibres represent terminations of axons reaching the cerebellum from the inferior olivary complex (Figure 12.6). They pass through the granular layer and the Purkinje cell layer to reach the molecular layer. Each climbing fibre becomes intimately associated with the proximal part of the dendritic tree of one Purkinje cell, and establishes numerous synapses on them. (These are called climbing fibres as they appear to ***climb up*** along the Purkinje cell dendrites).

Efferent Fibres

The efferent fibres from the cerebellar cortex are axons of Purkinje cells, which terminate in the cerebellar (central) nuclei. Some efferents from the flocculonodular lobe bypass the cerebellar nuclei and terminate in the brainstem nuclei. Axons of the Purkinje cells are inhibitory to cerebellar nuclei.

The fibres from dentate, emboliform, and globose nuclei leave cerebellum through the superior cerebellar peduncle. The fibres from the fastigial nucleus leave the cerebellum through inferior cerebellar peduncle.

The intrinsic neuronal circuit of cerebellum is shown in Figure 11.11.

CONNECTIONS OF CEREBELLUM

The fundamental points to be appreciated in considering the connections of the cerebellum are, as a rule, as follows:

- Afferent fibres terminate in the cortex
- Efferent fibres arising in the cortex end in cerebellar nuclei

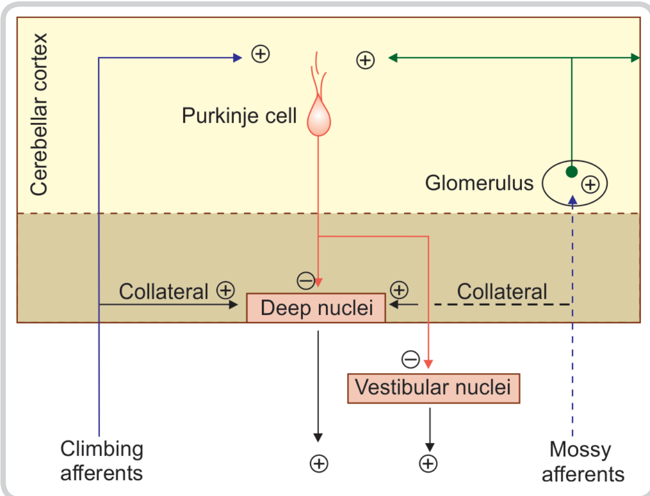

Figure 11.11: Scheme to show the intrinsic neuronal circuitry of cerebellum

- Fibres arising in the nuclei project to centres outside the cerebellum.

The important exception to this rule is that some vestibular fibres project directly to the cerebellar nuclei. Some parts of the cortex give off efferents that bypass the nuclei to reach vestibular nuclei outside the cerebellum. That is why, vestibular nucleus is considered as displaced cerebellar nucleus.

The main afferent input, from periphery, received by cerebellum, are proprioception, exteroception, vision and from vestibular apparatus. The integrative input comes from cerebral cortex, reticular formation and inferior olivary complex.

The main efferents from cerebellum go via thalamus to the cerebral cortex. Other outputs go to the red nucleus, reticular formation and vestibular nuclei.

CEREBELLAR PEDUNCLES

The various fibres entering or leaving the cerebellum pass through the superior, middle, and inferior cerebellar peduncles. These connect the cerebellum to the midbrain, the pons, and the medulla, respectively (Figure 11.12).

Superior Cerebellar Peduncle

The superior cerebellar peduncle consists mainly of fibres arising in cerebellar nuclei (mainly the dentate nucleus). The fibres pass forwards, upwards, and medially, lying along the upper and lateral margin of the rhomboid fossa. The right and left peduncles are connected by a thin lamina of white matter, the ***superior (or anterior) medullary velum***. Along with the velum the peduncles form the upper part of the roof of the fourth ventricle. The fibres of the peduncle enter the midbrain and cross to the opposite side before ending (mainly) in the red nucleus. Many of the fibres ascend to the thalamus. The fibres comprising the superior cerebellar peduncle are enumerated in Table 11.4.

Middle Cerebellar Peduncle

The middle cerebellar peduncle is the largest of the three peduncles. It begins as a lateral continuation of the ventral part of the pons. Its fibres, which arise in pontine nuclei, cross to the opposite side. The fibres of the peduncle form a thick bundle that passes laterally and backwards to enter the white core of the cerebellum through the horizontal fissure. On entering the cerebellum the fibres are placed lateral to those of the inferior peduncle (the superior peduncle being still more medial in position).

Middle cerebellar peduncles consists of only afferent fibres which transmit the impulses from pontine nuclei to the opposite cerebellar hemisphere (pontocerebellar fibres).

Inferior Cerebellar Peduncle

This peduncle is also called the ***restiform body***. This is a thick bundle of fibres that connects the posterolateral part of the medulla with the cerebellum. The peduncle passes upwards and laterally along the inferolateral margin of the rhomboid fossa. Near the upper end of the medulla the peduncle lies between the superior cerebellar peduncle (on its medial side) and the middle cerebellar peduncle (laterally). The inferior peduncle then turns sharply backwards to enter the while core of the cerebellum.

Over the medial part of the inferior cerebellar peduncle there are fibres that pass through the vestibular nuclei before entering the cerebellum. These fibres constitute the ***juxtarestiform body***.

The fibres comprising the inferior cerebellar peduncle are enumerated in Table 11.4.

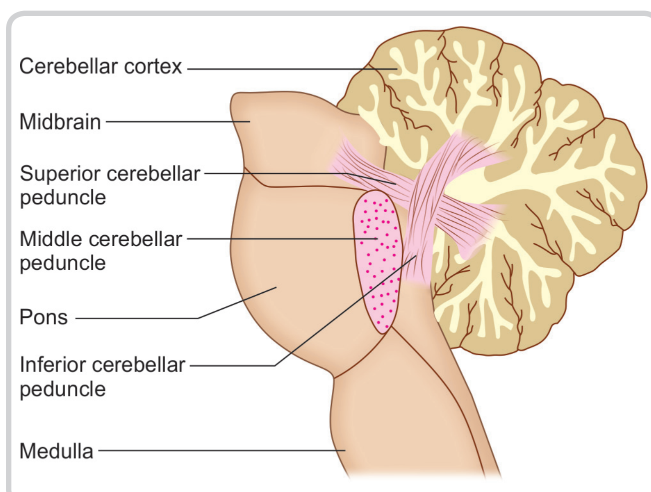

Figure 11.12: Illustration showing cerebellar peduncles

Table 11.4 | Tracts in Cerebellar Peduncles and their Functions

S.No	Tract	Functions
	Superior Cerebellar Peduncle	
A. Fibres entering the cerebellum		
1	Ventral spinocerebellar tract	Proprioception and exteroception (lower limb)
2	Tectocerebellar fibres	Visual input
3	Trigeminocerebellar fibres	Proprioception from mesencephalic nucleus
4	Hypothalamocerebellar fibres	Somatic visceral integration
5	Coerulocerebellar fibres	Noradrenergic modulation of cerebellar learning
B. Fibres leaving the cerebellum		
1	Cerebellorubral fibres	From the dentate, emboliform and globose nuclei for fine motor coordination and muscle tone
2	Cerebellothalamic fibres	
3	Cerebelloreticular	Somatomotor and autonomic modulation
4	Cerebello-olivary fibres	GABAergic feedback
5	Cerebellohypothalamic fibres	Cerebellar autonomic modulation
	Middle Cerebellar Peduncle	
1	Pontocerebellar fibres	Corticopontocerebellar pathway for motor planning
2	Serotoninergic fibres	Modulates the responses of other neurotransmitters
	Inferior Cerebellar Peduncle	
A. Fibres entering the cerebellum		
1	Posterior spinocerebellar tract	Proprioception and exteroception (lower limb)
2	Cuneocerebellar tract (posterior external arcuate fibres)	Proprioception and exteroception (upper limb)
3	Olivocerebellar fibres	***Climbing*** fibres from inferior olivary and accessory olivary nucleus for cerebellar learning
4	Parolivocerebellar fibres	
5	Reticulocerebellar fibres	Feedback from entire central nervous system: spinal cord to cortex
6	Vestibulocerebellar fibres	Information about head position in its movement
7	Anterior external arcuate fibres	From arcuate nuclei, which are displaced pontine nuclei (cortico-arcuato-cerebellar pathways)
8	Fibres of striae medullares	
9	Trigeminocerebellar fibres	Exteroception (main sensory and spinal nuclei)
B. Fibres leaving the cerebellum		
1	Cerebello-olivary fibres	GABAergic feedback
2	Cerebellovestibular fibres	Regulates body equilibrium
3	Cerebelloreticular fibres	Somatomotor modulation
	Fibres in all the above mentioned efferent tracts in inferior cerebellar peduncle arise from the fastigial nucleus	

CONNECTIONS BETWEEN CEREBELLUM AND SPINAL CORD

From a clinical point of view, the most important connections of the cerebellum are with the spinal cord and with the cerebral cortex. These connections are through various pathways that are summarized below.

Spinocerebellar pathways convey to the cerebellum proprioceptive information necessary for controlling muscle tone and for maintaining body posture. These pathways also carry exteroceptive impulses.

- ***Direct pathways from spinal cord to cerebellum:*** These are the ventral spinocerebellar and the dorsal spinocerebellar tract which convey information from the hind limb. Information from the forelimb is conveyed by the cuneocerebellar tract. The cuneocerebellar tract begins in the medulla and is functionally equivalent to spinocerebellar tracts.
- ***Indirect pathways from spinal cord to cerebellum:*** These are as follows:
  - Spino-olivocerebellar
  - Spinoreticulocerebellar

- Spinovestibulocerebellar
- Spinotectocerebellar pathways.

Although these are not concerned with the spinal cord it is useful to consider here the pathways that carry impulses from tissues in the head to the cerebellum. Exteroceptive impulses from the head (and parts of the neck) reach the cerebellum through trigemino-cerebellar fibres arising in the main sensory and spinal nuclei of this nerve. Fibres from the mesencephalic nucleus convey proprioceptive information from the muscles of mastication to the cerebellum.

- ***Cerebellospinal pathways:*** The cerebellum influences the spinal cord through the following pathways:
  - Cerebellorubrospinal
  - Cerebellovestibulospinal
  - Cerebelloreticulospinal
  - Cerebellotectospinal
  - Cerebellothalamocorticospinal.

CONNECTIONS BETWEEN CEREBELLUM AND CEREBRAL CORTEX

The connections between the cerebellum and the cerebral cortex are all indirect.

- ***Corticocerebellar pathways:*** The cerebral cortex influences the cerebellum through various centres in the brainstem through the following pathways:
  - ***Corticopontocerebellar pathway:*** This is the most important of the corticocerebellar pathway. The arcuate nuclei and the pontobulbar body represent displaced pontine nuclei. The corticoarcuato-cerebellar, and the corticopontobulbar-cerebellar pathways are functionally equivalent to the cortico-pontocerebellar pathway.
  - Cortico-olivocerebellar
  - Corticoreticulocerebellar
  - Corticorubrocerebellar
  - Corticotectocerebellar

  Some of the impulses may reach these intermediary centres through the corpus striatum.
- ***Cerebellocortical pathways:*** The cerebellum projects upon the cerebellar nuclei from where fibres relay to the thalamus. Thalamocortical fibres then convey these impulses to the cerebral cortex. Cerebellar connection reaches the cerebral cortex through cerebelloreticulo-thalamocortical pathway also.

Connections and functions of Cerebellar Nuclei are summarised in Table 11.5.

FUNCTIONS OF CEREBELLUM

The cerebellum plays an essential role in the control of movement. It is responsible for ensuring that movement takes place smoothly, in the right direction and to the right extent. Cerebellar stimulation modifies movements produced by stimulation of motor areas of the cerebral cortex. The cerebellar cortex is also important for learning of movements (for example, in learning to write).

Through its vestibular and spinal connections, the cerebellum is responsible for maintaining the equilibrium of the body.

These functions are possible because the cerebellum constantly receives proprioceptive information regarding the state of contraction of muscles and of the position of various joints. It also receives information from the eyes, the ears, the vestibular apparatus, the reticular formation, and the cerebral cortex. All this information is integrated and is used to influence movement through motor centres

Table 11.5 | Connections and Functions of the Nuclei of the Cerebellum

Nucleus	Afferent	Efferent	Functions
Nucleus fastigii	• Vestibular apparatus through the vestibular nerve • Vestibulocerebellum, i.e., vermis and flocculonodular lobe	• To vestibular nuclei • To reticular formation of the medulla • To thalamus • To midbrain (red nucleus, central grey matter—nucleus of Darkschewitsch) • To visceral centres in brainstem • To medial accessory and main inferior olivary nuclei	Control of muscle action (axial and proximal limb muscles) in response to labyrinthine stimuli
Nucleus emboliform and nucleus globose	From the paravermal area or spinocerebellum	• To red nucleus • To thalamus • To reticular formation • To pontine nuclei • To dorsal accessory olivary nucleus	Controls crude movements of the limbs
Nucleus dentate	From neocerebellum or the lateral part of cerebellar hemisphere	• To thalamus • To red nucleus • To oculomotor nucleus • To inferior olivary nucleus • To reticular formation	Controls highly skilled voluntary movements of precision

in the brainstem and spinal cord and also through the cerebral cortex.

Functional Localization in Cerebellum

In the cerebellar cortex it is possible to localize areas that receive afferents from different parts of the body. There is a double representation, one on the superior surface and one on the inferior surface of the cerebellum. Representation on the superior surface is ipsilateral; and that on the inferior surface is bilateral. On either surface the anteroposterior sequence of parts represented is leg, trunk, arm and head. These areas are located in vermal and paravermal areas (paleocerebellum) and correspond to areas that receive fibres from the spinal cord. Stimulation of these areas produces movements in parts of the body that correspond roughly to those from which sensory impulses are received.

In addition to proprioceptive impulses the cerebellum receives visual impulses which reach the folium and tuber. A second visual area is located in the biventral lobule and tonsil. These visual areas also receive auditory impulses. Vestibular impulses are received mainly by the uvula, nodule and flocculus (vestibulocerebellum).

CEREBELLUM AND LEARNING

The cerebellum is concerned with learned adjustments that make coordination easier when a given motor task is performed over and over. As a task is being learned, activity in the brain shifts from the prefrontal areas to the basal nuclei and the cerebellum. The tasks where the neocerebellum, most clearly comes into play, are those where it is necessary to make fine adjustments to the way an action is performed.

The basis of the learning in the cerebellum is through the input via the inferior olivary complex (the only climbing fibre input). Each Purkinje cell receives inputs from 250,000 to 1 million mossy fibres, but each has only a single climbing fibre from the inferior olive, and this fibre makes 2000 to 3000 synapses on the Purkinje cell. Climbing fibre activity is increased when a new movement is being learned, and selective lesions of the olivary complex abolish the ability to produce long-term adjustments in certain motor responses.

During motor learning, climbing fibre activation produces a large, complex spike in the Purkinje cell and this spike produces a long-term modification of the pattern of mossy fibre input to that particular Purkinje cell. This is especially so, when there was a mismatch between an intended movement and the movement that was actually executed. Climbing fibre activity acts as an error signal, and may cause synchronously activated parallel fibre inputs to be weakened. Climbing fibres thus provide a teaching signal that induces synaptic modification in parallel fibre-Purkinje cell synapses. This explains why net practice is so important prior to playing cricket matches at an international level!

NEUROCHEMISTRY OF CEREBELLUM

- Neuroactive substances present in the cerebellum include, mainly, glutamate, GABA, serotonin, noradrenalin, acetyl choline and glycine.
- The main neurotransmitter in the cerebellum is glutamate. Afferents reaching Purkinje cells through climbing fibres and through the mossy fibre — granule cell — parallel fibre system are glutamatergic. They are excitatory. Some mossy fibres arising in vestibular nuclei are cholinergic. Some reticulocerebellar fibres are serotoninergic, while coeruleo-cerebellar fibres are noradrenergic.
- Purkinje cells themselves are GABAergic and are inhibitory to cerebellar (and vestibular) nuclei.
- Golgi cells, stellate cells and basket cells are GABAergic.
- Neurons in cerebellar nuclei are glutamatergic (excitatory). Some neurons in cerebellar nuclei are glycinergic. These are interneurons and may contain GABA in addition to glycine.

Some Quantitative Data regarding the Cerebellar Cortex

Extensive researches have revealed interesting quantitative data about the cerebellar cortex as follows:

- The cerebellar cortex has a total surface area of approximately 200,000 square millimeters.
- The cortex underlying each square millimetre of surface area contains:
  - about 500 Purkinje neurons
  - about 600 basket cells
  - about 50 Golgi neurons
  - about 3,000,000 granule cells
  - about 600,000 glomeruli.
- Each axon reaching the cerebellar cortex from the olive divides into about ten climbing fibres. Each olivary neuron, therefore, establishes connections with about ten Purkinje cells.
- Each mossy fibre synapses with about 400 granule cells. The axons of each granule cell synapse with about 300 to 450 Purkinje neurons.
- Each Purkinje neuron may bear up to 80,000 synapses with different parallel fibres. The dendritic tree of a single Purkinje cell may be crossed by about 250,000 parallel fibres.

The total number of neurons in cerebellum exceeds that of the rest of the brain put together!

ARTERIAL SUPPLY OF CEREBELLUM

The cerebellum is supplied by three pairs of cerebellar arteries:

- ***Superior cerebellar artery***: A branch of basilar artery supplies the superior surface of the cerebellum.
- ***Anterior inferior cerebellar artery***: A branch of basilar artery supplies the anterior part of the inferior surface of the cerebellum.
- ***Posterior inferior cerebellar artery***: A branch of vertebral artery supplies the posterior part of the inferior surface of the cerebellum.

Clinical Correlation

Disorders of equilibrium

The maintenance of equilibrium and correct posture is dependent on reflex arcs involving various centres including the spinal cord, the cerebellum, and the vestibular nuclei. Afferent impulses for these reflexes are carried by the posterior column tracts (fasciculus gracilis and fasciculus cuneatus), the spinocerebellar tracts, and others. Efferents reach neurons of the ventral grey column (anterior horn cells) through rubrospinal, vestibulospinal, and other 'extrapyramidal' tracts. Interruption of any of these pathways or lesions in the cerebellum, the vestibular nuclei and other centres concerned; can result in various abnormalities involving maintenance of posture and coordination of movements.

Cerebellar syndrome

The cerebellar lesions due to trauma, haemorrhage, tumours, etc. produce a number of signs and symptoms, which together constitute the ***cerebellar syndrome.***

The signs and symptoms produced by cerebellar lesions are as follows:

- ***Ataxia:*** Inability to maintain the equilibrium of the body, while standing, or while walking, is referred to as ***ataxia.*** This may occur as a result of the interruption of afferent proprioceptive pathways (***sensory ataxia***). Disease of the cerebellum itself, or of efferent pathways, results in more severe disability. Coordination of the activity of different groups of muscles is interfered with, leading to various defects. The person is unable to stand with his/her feet close together: the body sways from side to side and the person may fall. While walking, the patient staggers and is unable to maintain progression in the desired direction. Lack of proprioceptive information can be compensated to a considerable extent by information received through the eyes. The defects mentioned are, therefore, much more pronounced with the eyes closed (***Romberg's sign***).
- ***Asynergia:*** Lack of coordination of muscles also interferes with purposeful movements (***asynergia***). Movements are jerky and lack precision. For example, the patient finds it difficult to touch his nose with a finger, or to move a finger along a line. There is difficulty in performing movements involving rapid alternating action of opposing groups of muscles (for example, tapping one hand with the other; repeated pronation and supination of the forearm). This phenomenon is called ***dysdiadokokinesis.***
- ***Dysarthria:*** Incoordination of the muscles responsible for the articulation of words leads to characteristic speech defects (***dysarthria***).
- ***Nystagmus:*** For the same reason, the eyes are unable to fix the gaze on an object for any length of time. Attempts to bring the gaze back to the same point result in repeated jerky movements of the eyes. This is called ***nystagmus.***
- ***Hypotonia:*** Apart from incoordination, cerebellar disease is characterized by diminished muscle tone (***hypotonia***).
- ***Asthenia:*** The muscles are soft, and tire easily. Joints may lack stability (***flail joints***).
- ***Reflexes:*** Tendon reflexes may be diminished. Alternatively, tapping a tendon may result in oscillating movements of the part concerned like a pendulum.

Attempts have been made to correlate symptoms of cerbellar damage with different regions of the cerebellum but without much success. Some correlations are as follows:

- When the flocculus, nodule, and uvula are damaged (***flocculonodular syndrome***) the main symptom is imbalance. Remember that the connections of the flocculonodular lobe are predominantly vestibular.
- Small lesions in the cerebellar cortex may produce no effect. Extensive lesions are marked by hypotonia and incoordination (on the side of the lesion).
- Intention tremor and staggering appear when the dentate nucleus or the superior cerebellar peduncle (which carries fibres from the nucleus) is damaged.

The cerebellopontine angle

This is a small triangle interval bounded by the pons (anteromedially) and the cerebellum (posteromedially). A tumour in this space produces characteristic symptoms.

- Pressure on the spinal nucleus of the trigeminal nerve leads to loss of sensations of pain and temperature over the face.
- Pressure on fibres and nucleus of the facial nerve results in facial paralysis.
- Pressure on the middle cerebellar peduncle leads to ataxia.
- Pressure on fibres and nucleus of vestibulocochlear nerve results in vertigo, tinnitus, nystagmus and deafness.

CEREBELLUM: THE RULE OF THREE

There are several aspects of cerebellum that run in threes!

1	Subdivisions	Left hemisphere	Vermis	Right hemisphere
2	Fissures	Posterolateral	Primary	Horizontal
3	Lobes	Anterior	Posterior	Flocculonodular
4	Developmental	Archicerebellum	Paleocerebellum	Neocerebellum
5	Connections	Vestibular	Spinal cord	Cerebral cortex
6	Functions	Body equilibrium	Muscle tone	Fine co-ordination of voluntary movements
7	Longitudinal subdivisions	Vermal	Paravermal	Lateral
8	Core subdivisions	Cerebellar cortex	Cerebellar white matter	Deep cerebellar nuclei
9	Cerebellar cortex	Molecular layer	Purkinje cell layer	Granular layer
10	Cerebellar glomeruli	Axon of a mossy fibre	Dendrites of granule cells	Axon and dendrite of Golgi cell
11	Cerebellar white matter	Commissural fibres	Association fibres	Projection fibres
12	Cerebellar peduncles (old names within brackets)	Superior (brachium conjunctivum)	Middle (brachium pontis)	Inferior (restiform and juxtarestiform body)
13	Brainstem connected	Midbrain	Pons	Medulla oblongata
14	Deep cerebellar nuclei	Dentate	Emboliform and globose (nucleus interpositus)	Fastigial
15	Arterial supply	Posterior inferior cerebellar	Anterior inferior cerebellar	Superior cerebellar

Multiple Choice Questions

1. Which one of the following fissures divides the cerebellum into anterior and posterior lobes?
A. Horizontal
B. Primary
C. Posterolateral
D. Secondary

2. Which one of the following is a part of the paleocerebellum?
A. Flocculus
B. Lingula
C. Nodule
D. Uvula

3. The deep furrow separating the cerebellar hemispheres inferiorly is known as
A. Cerebellar notch
B. Fissura prima
C. Vallecula
D. Vermis

4. The neocerebellum is concerned with
A. Regulation of muscle tone of limbs
B. Maintenance of equilibrium
C. Regulation of muscle tone of trunk
D. Smooth performance of skilled acts

5. Most of the efferents of the cerebellum are projected to the
A. Midbrain
B. Pons
C. Medulla oblongata
D. Spinal cord

6. The excitatory neurons of the cerebellar cortex are
A. Basket
B. Granule
C. Golgi
D. Stellate

7. The pathway that passes through the middle cerebellar peduncle is
A. Anterior spinocerebellar
B. Pontocerebellar
C. Posterior spinocerebellar
D. Tectocerebellar

8. The dendrites of Purkinje cells of the cerebellar cortex synapse with the axons of
A. Deep cerebellar nuclei
B. Golgi cells
C. Mossy fibres
D. Granule cells

9. Which one of the following neurons forms the sole output neurons of the cerebellar cortex?
A. Basket
B. Golgi
C. Purkinje
D. Stellate

10. The axons of the Purkinje cells end mainly in the
A. Cerebellar nuclei
B. Midbrain
C. Pons
D. Medulla oblongata

Answers

1. B **2.** D **3.** C **4.** D **5.** A **6.** B **7.** B **8.** D **9.** C **10.** A

Chapter 12

Diencephalon

Specific Learning Objectives

At the end of learning, the student shall be able to:
- Enumerate the subdivisions of the diencephalon
- Describe the structure, nuclei, connections and functions of thalamus
- Describe the structure, nuclei, connections and functions of hypothalamus

INTRODUCTION

The diencephalon is the part of the brain between the cerebrum above and midbrain below. It extends from the interventricular foramen to posterior commissure. The hypothalamic sulcus divides the diencephalon into two parts—dorsal (***pars dorsalis***) and ventral part (***pars ventralis***).

- ***Pars dorsalis*** consists of the thalamus, metathalamus, and epithalamus
- ***Pars ventralis*** consists of the hypothalamus and subthalamus.

The cavity of the diencephalon is the third ventricle. The subdivisions of the diencephalon and nuclei to be found in each division are summarized in Table 12.1.

Table 12.1 | Divisions and Subdivisions of Diencephalon

Divisions	Subdivisions
Pars dorsalis	
• Thalamus (dorsal thalamus)	
• Metathalamus	Medial and lateral geniculate bodies
• Epithalamus	Pineal gland (body) and habenular nuclei
Pars ventralis	
• Subthalamus (ventral thalamus)	Subthalamic nucleus and zona incerta
• Hypothalamus	

Note: The medial and lateral geniculate bodies are distinct from the other regions of the thalamus and are grouped together as the metathalamus and are integral parts of the dorsal thalamus.

The subthalamic nucleus is included with the basal nuclei to which it is closely related functionally.

THALAMUS (DORSAL THALAMUS)

Anatomically, the thalamus (or dorsal thalamus) is a large egg-shaped mass of grey matter that lies immediately lateral to the third ventricle (Figures 12.1 and 12.2).

External Features

It has two ends (or poles), anterior and posterior; and four surfaces, superior, inferior, medial, and lateral.

The ***anterior end (or pole)*** lies just behind the interventricular foramen. The ***posterior end (or pole)*** is called the ***pulvinar***. It lies just above and lateral to the superior colliculus. The pulvinar is separated from the geniculate bodies by the ***superior brachium quadrigeminum***.

The ***medial surface*** forms the greater part of the lateral wall of the third ventricle and is lined by ependyma. The medial surfaces of the two thalami are usually interconnected by a mass of grey matter called the ***interthalamic adhesion (connexus)*** (Figure 12.1). Inferiorly, the medial surface is separated from the hypothalamus by the ***hypothalamic sulcus***. This sulcus runs from the interventricular foramen to the aqueduct (Figure 12.1).

The ***lateral surface*** of the thalamus is related to the internal capsule, which separates it from the lentiform nucleus (Figure 12.1).

The ***superior (or dorsal) surface*** of the thalamus is related laterally to the caudate nucleus, from which it is separated by a bundle of fibres called the ***stria terminalis***, and by the thalamostriate vein. The thalamus and the caudate nucleus together form the floor of the central part of the lateral ventricle (Figure 12.2). The medial part of the superior surface of the thalamus is, however, separated from the ventricle by the fornix and by a fold of pia mater called the ***tela choroidea***.

The inferior surface of the thalamus is related to the hypothalamus, anteriorly and the ventral thalamus, posteriorly (Figure 12.2). The ventral thalamus separates the thalamus from the tegmentum of the midbrain.

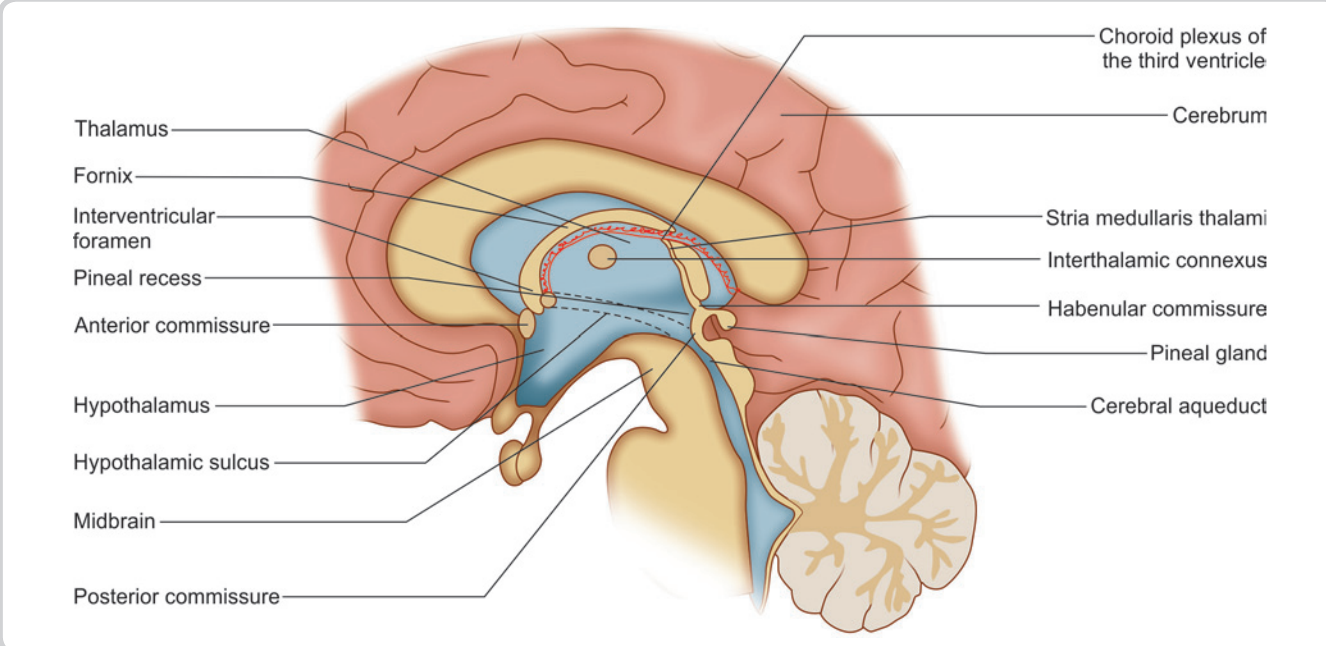

Figure 12.1: Midsagittal section of brain showing thalamus, hypothalamus and epithalamus

At the junction of the medial and superior surfaces of the thalamus, the ependyma of the third ventricle is reflected from the lateral wall to the roof. The line of reflection is marked by a line called the ***taenia thalami***. Underlying it there is a narrow bundle of fibres called the ***stria medullaris thalami (stria habenularis)***.

Internal Structure of Thalamus

The thalamus consists mainly of grey matter and only small amount of white matter.

White Matter

The superior surface of thalamus is covered by a thin layer of white matter called the ***stratum zonale*** and its lateral

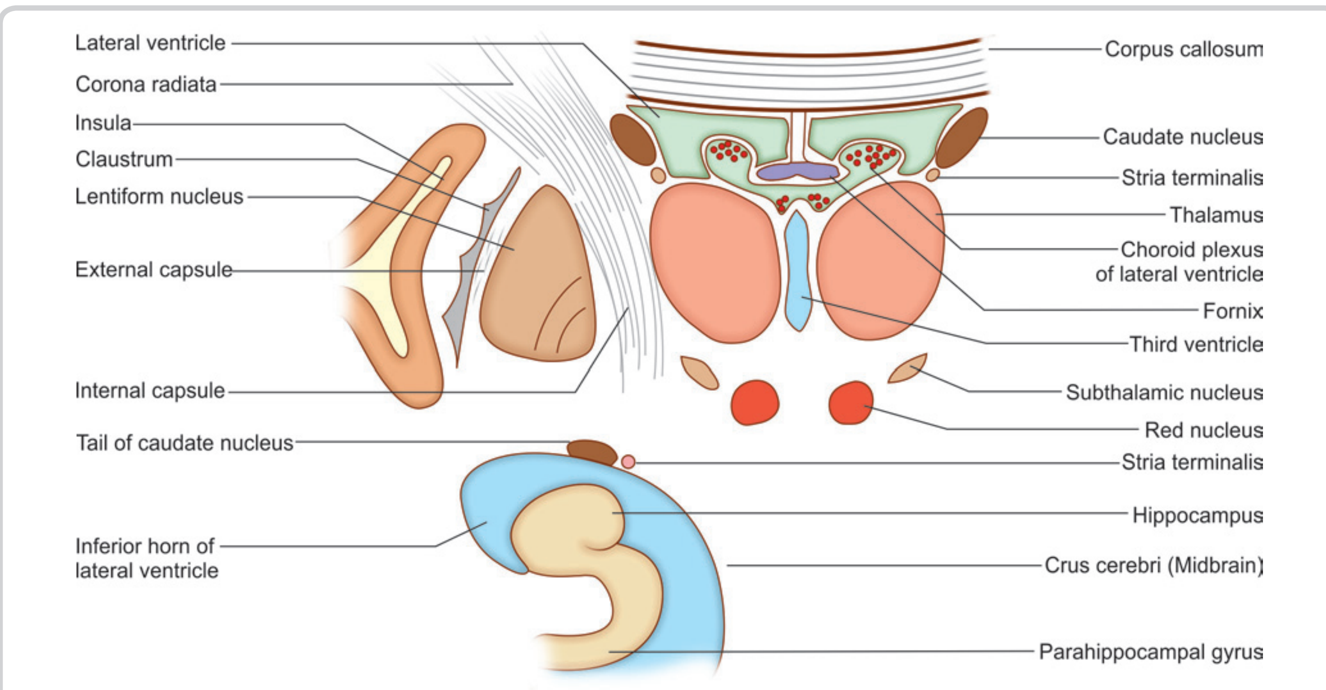

Figure 12.2: Coronal section through cerebrum shows structures related to thalamus

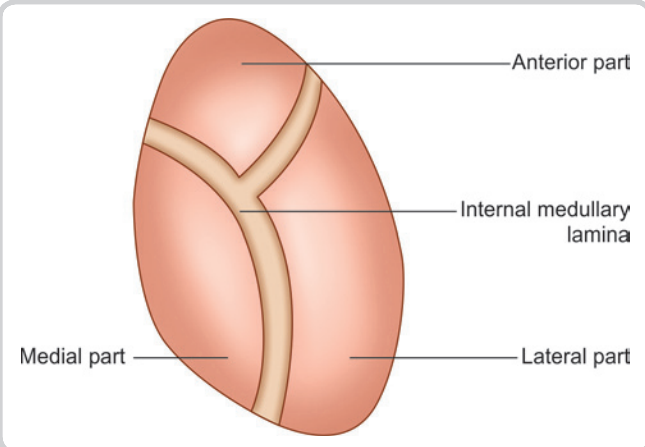

Figure 12.3: Schematic diagram showing a horizontal section of thalamus. Note: The Y-shaped internal medullary lamina divides the thalamus into anterior, lateral, and medial parts

Table 12.2 | Functional Classification of Nuclei of Thalamus

Motor relay group	• Ventral anterior nucleus • Ventral lateral nucleus
Sensory relay group	• Ventral posterolateral nucleus • Ventral posteromedial nucleus • Medial geniculate body • Lateral geniculate body
Sensory modulator group	• Lateral dorsal nucleus • Lateral posterior nucleus • Pulvinar
Limbic group	• Anterior nucleus • Medial dorsal nucleus
Non-specific thalamic group	• Intralaminar nuclei • Midline nuclei

surface, by a similar layer called the ***external medullary lamina.***

Grey Matter

The grey matter of the thalamus is subdivided into three main parts by a Y-shaped sheet of white matter, which is called the ***internal medullary lamina*** (Figure 12.3). This lamina is placed vertically. It divides the thalamus into lateral, medial, and anterior parts situated between the two limbs of the 'Y'.

A number of nuclei can be distinguished within each of these parts (Figures 12.4 and 12.5, and Table 12.2). Only the more important of these are listed below:

Nuclei in the Anterior Part

A number of nuclei can be distinguished, but they are collectively referred to as the ***anterior nucleus.***

Nuclei in the Medial Part

The largest of these is the ***medial dorsal nucleus.*** It is divisible into a ***magnocellular part*** (anteromedial) and a ***parvocellular part*** (posterolateral).

Nuclei in the Lateral Part

The nuclei in the lateral part can be subdivided into a ***ventral group*** and a ***lateral group*** (arranged in two tiers).

The ***nuclei in the ventral group*** are as follows (in anteroposterior order):

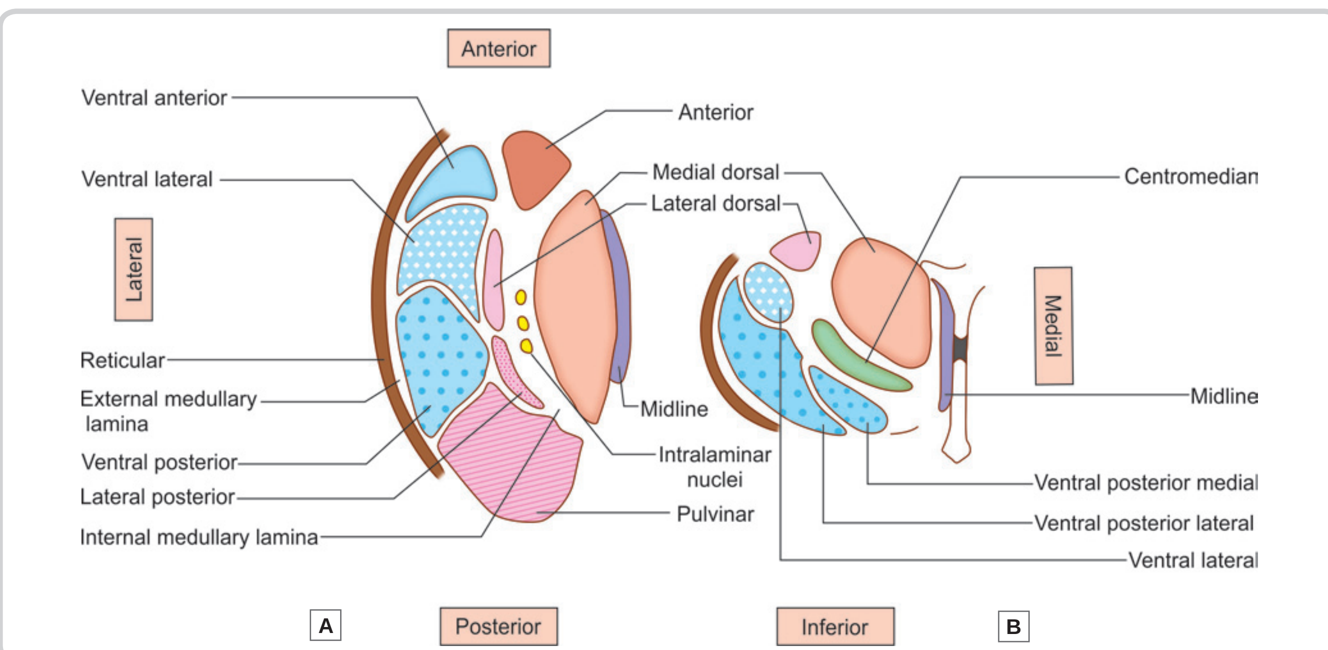

Figure 12.4: Scheme to show the nuclei of thalamus (**A**) Superior aspect (**B**) In coronal section

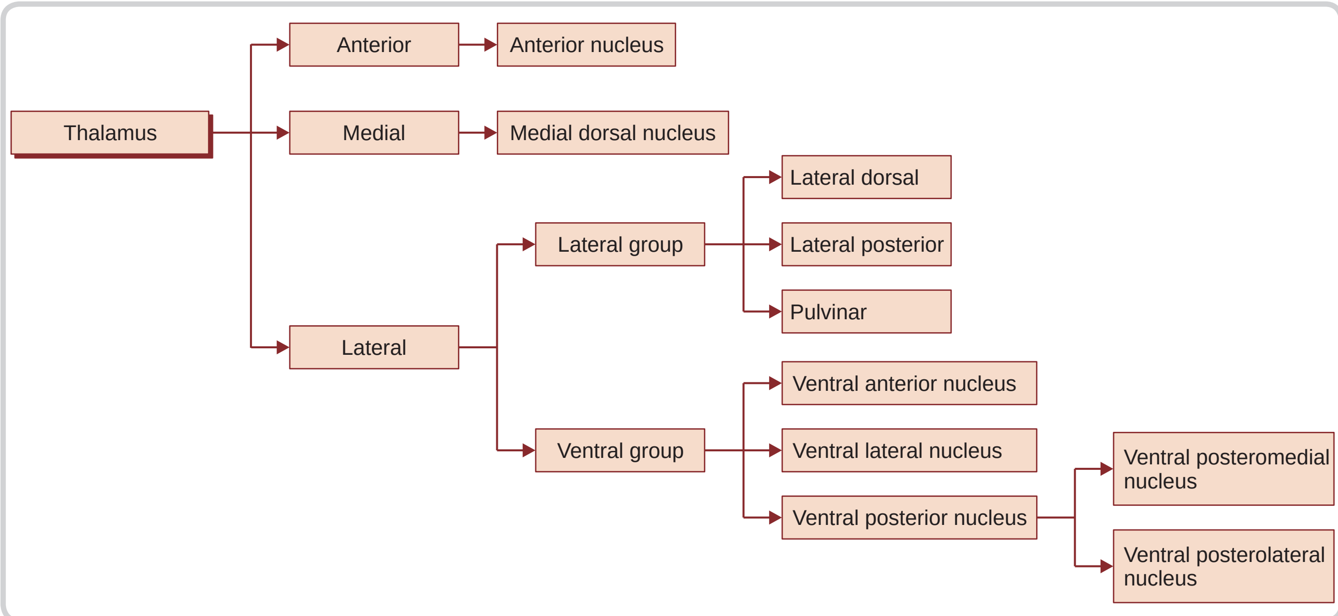

Figure 12.5: Flowchart showing subdivisions of thalamic nuclei

- ***Ventral anterior nucleus***
- ***Ventral lateral nucleus*** (also called the ***ventral intermediate nucleus***)
- ***Ventral posterior nucleus***, which is further subdivided into a lateral part, called the ***ventral posterolateral nucleus***, and a medial part, called the ***ventral posteromedial nucleus*** (Figure 12.4B).

The ***nuclei of the lateral group*** are as follows (in anteroposterior order):

- ***Lateral dorsal nucleus*** (or ***dorsolateral nucleus***)
- ***Lateral posterior nucleus***
- ***Pulvinar***

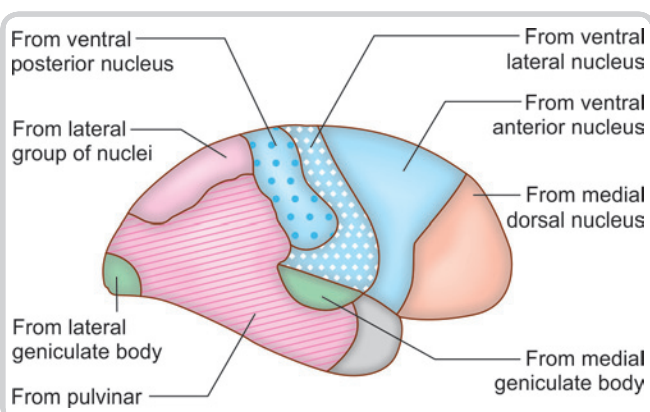

Figure 12.6: Diagram to show areas of cerebral cortex (superolateral surface) that are connected to individual thalamic nuclei–the connections are reciprocal. The anterior thalamic nuclei project mainly to the gyrus cinguli (not seen in this view) present on the medial surface of cortex

Other Thalamic Nuclei

In addition to the above, the thalamus contains the following nuclei:

- The ***intralaminar nuclei*** are embedded within the internal medullary lamina. There are several nuclei in this group. The most important of these is the ***centromedian nucleus*** (Figure 12.4B).
- The ***midline nuclei*** consist of scattered cells that lie between the medial part of the thalamus and the ependyma of the third ventricle. Several nuclei are recognized.
- The ***medial and lateral geniculate bodies*** (traditionally described under metathalamus) are now included as part of the thalamus.

The reticular nucleus, earlier described as part of the dorsal thalamus, is now regarded as part of the ventral thalamus.

Connections of Thalamus—An Overview

Afferent

Afferents from a large number of subcortical centres converge on the thalamus (Figure 12.7).

- Exteroceptive and proprioceptive impulses ascend to it through the medial lemniscus, the spinothalamic tracts, and the trigeminothalamic tract
- Visual and auditory impulses reach the lateral and medial geniculate bodies, respectively
- Sensations of taste are conveyed to the thalamus through solitariothalamic fibres
- ***Olfactory impulses:*** Although the thalamus does not receive direct olfactory impulses they probably reach it through the amygdaloid complex

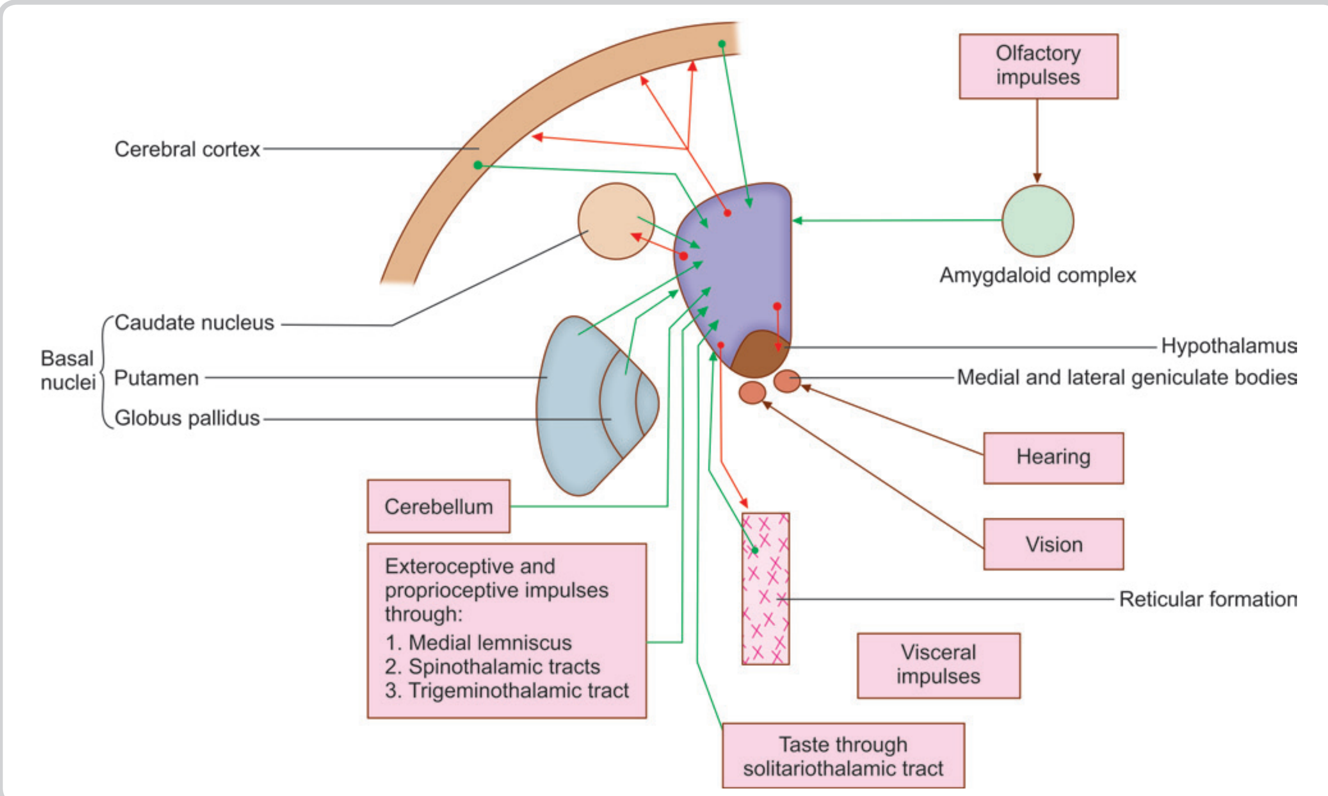

Figure 12.7: Scheme to show the main connections of thalamus (as a whole)

- Visceral information is conveyed from the hypothalamus and probably through the reticular formation
- In addition to these afferents, the thalamus receives profuse connections from all parts of the cerebral cortex, the cerebellum, and the corpus striatum.

The thalamus is, therefore, regarded as a great integrating centre where information from all these sources is brought together.

Efferent

The information received by thalamus is projected to almost the whole of the cerebral cortex through profuse thalamocortical projections (Figure 12.6). Thalamocortical fibres form large bundles that are described as ***thalamic radiations*** or as ***thalamic peduncles***. These radiations are ***anterior*** (or ***frontal***), ***superior*** (or ***dorsal***), ***posterior*** (or ***caudal***), and ***ventral.*** Efferent projections from the thalamus also reach the corpus striatum, the hypothalamus, and the reticular formation.

CONNECTIONS OF DIFFERENT PARTS OF THALAMUS

Connections of the Lateral Part of Thalamus

The lateral part of thalamus is made up of ventral and lateral groups of nuclei.

Connections of Ventral Group of Nuclei

From a clinical point of view, the most important connections of the thalamus are those of the ***ventral posterior nucleus.*** This nucleus is divisible into ventral posterolateral and ventral posteromedial parts (that are sometimes mentioned as separate nuclei). This nucleus receives the terminations of the major sensory pathways ascending from the spinal cord and brainstem (Figure 12.8). These include the medial lemniscus, the spinothalamic tracts, the trigeminal lemniscus, and the solitariothalamic fibres carrying sensations of taste.

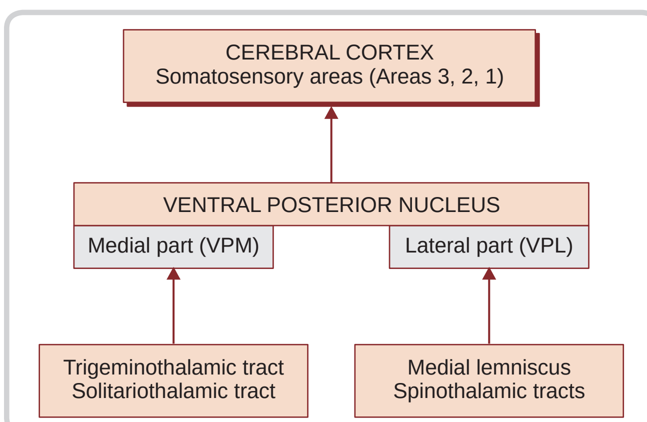

Figure 12.8: Connections of the ventral posterior nucleus of thalamus

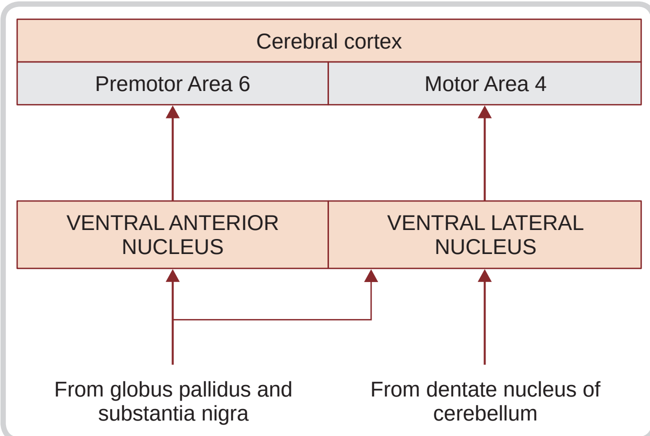

Figure 12.9: Connections of the ventral anterior and ventral lateral nucleus of thalamus

Within the nucleus, fibres from different parts of the body terminate in a definite sequence. The fibres from the lowest parts of the body end in the most lateral part of the nucleus. The medial lemniscus and spinothalamic tracts carrying sensations from the limbs and trunk end in the ventral posterolateral part, while the trigeminal fibres (from the head) end in the ventral posteromedial part, which also receives the fibres for taste. Different layers of cells within the nucleus respond to different modalities of sensation.

All the sensations reaching the nucleus are carried primarily to the sensory area of the cerebral cortex (SI, areas 3,2,1) by fibres passing through the posterior limb of the internal capsule (superior thalamic radiation). They also reach the second somatosensory area (SII) located in the parietal operculum (of the insula).

The ***ventral anterior nucleus*** receives fibres from the globus pallidus and substantia nigra pars reticularis and sends efferents to the premotor and supplemental motor areas of the cerebral cortex (Figure 12.9).

The ***ventral lateral nucleus*** receives afferents from dentate nucleus of cerebellum. It also receives fibres from the globus pallidus. Efferents from this nucleus project to motor area of the cerebral cortex.

Clinical Correlation

Ablation of the posterior part of ventral lateral nucleus can reduce tremors in parkinsonism.

Connections of Lateral Group of Nuclei

The ***lateral dorsal nucleus*** receives impulses from other thalamic nuclei (mainly from the medial and anterior group) (Figure 12.10). Efferent projections reach the limbic lobe—cingulate gyrus, the parahippocampal gyrus, and the hippocampal formation.

The ***lateral posterior nucleus*** receives fibres from other thalamic nuclei (mainly from the ventral posterior group). Efferents reach the cerebral cortex of the superior parietal lobule.

The ***pulvinar*** receives fibres from the lateral geniculate body, medial geniculate body and the superior colliculus. Efferents from the pulvinar project to extrastriate visual areas in the occipital and parietal lobes; and to visual and audiory association areas in the posterior part of the temporal lobe. The pulvinar is described as a lower visual centre.

Connections of Anterior Group of Thalamic Nuclei

The ***anterior nucleus*** is a part of circuit of Papez for recent memory. It receives fibres from the mammillary body through the mammillothalamic tract. Efferent fibres project to the gyrus cinguli (Figure 12.11).

Connections of Medial Group of Thalamic Nuclei

The ***medial dorsal nucleus*** (the large nucleus in the medial group) is involved in controlling emotional states. This nucleus is concerned with mediation of visceral and somatic reflexes. Damage to the nucleus leads to decrease in anxiety, tension and aggression. These functions are similar to those of the prefrontal cortex (Figure 12.12).

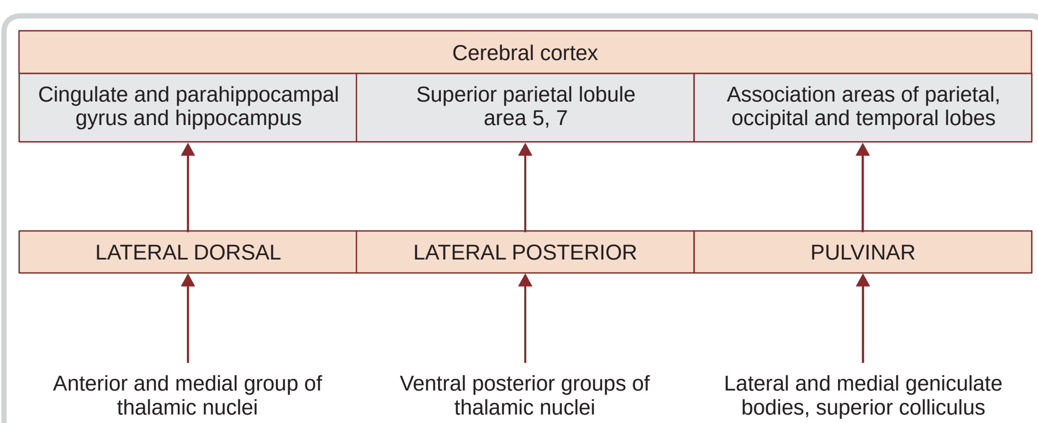

Figure 12.10: Connections of the lateral group of thalamic nuclei

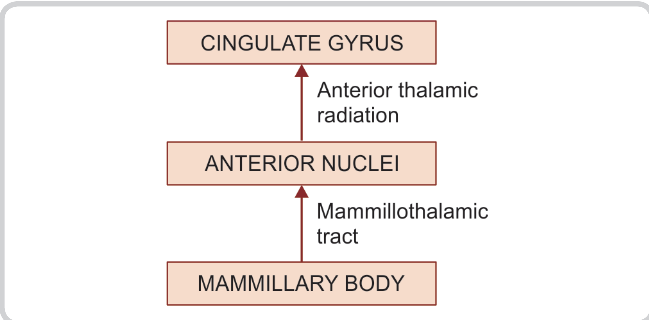

Figure 12.11: Connections of the anterior group of thalamic nuclei

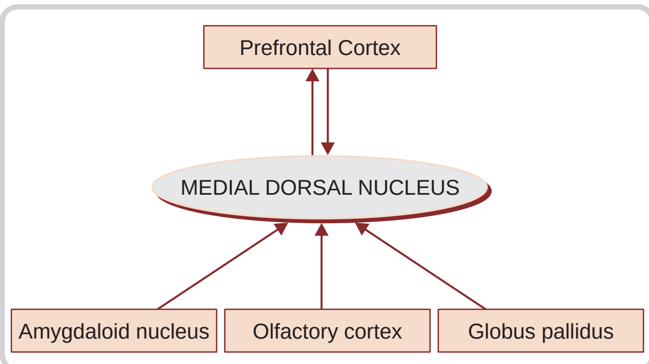

Figure 12.12: Connections of the medial dorsal nucleus of thalamus

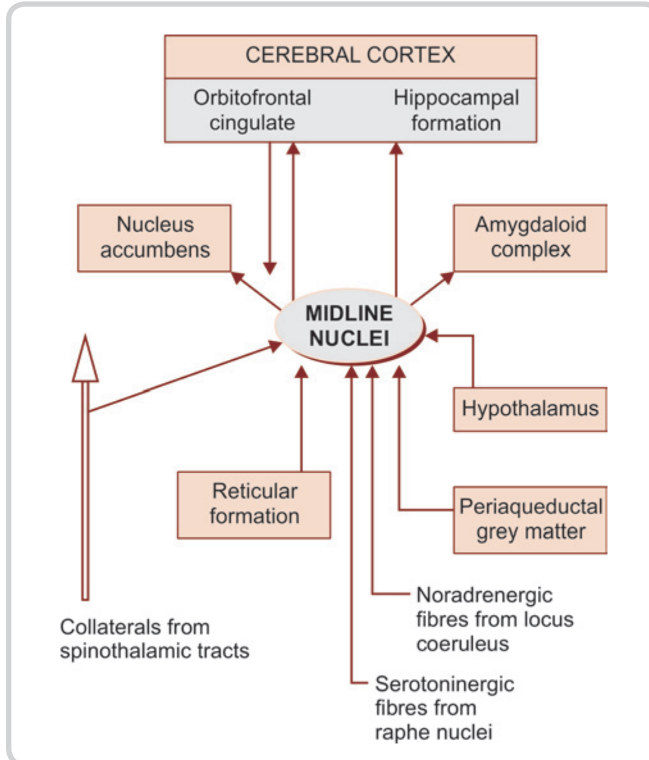

Figure 12.14: Connections of the midline nuclei of thalamus

Other Connections

Intralaminar nuclei: There are several nuclei in this group divided into subgroups: anterior and posterior. The posterior subgroup includes the large centromedian nucleus. The nuclei of this group receive inputs from the body through collaterals of spinothalamic tracts (Figure 12.13). Fibres are also received from the reticular formation, the cerebellar nuclei, and the substantia nigra. The centromedian nucleus receives many fibres from the globus pallidus.

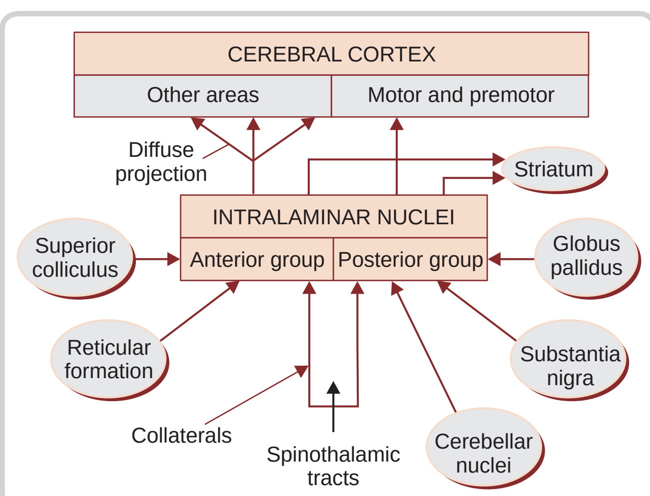

Figure 12.13: Connections of intralaminar thalamic nuclei

Efferents from intralaminar nuclei reach the cerebral cortex. Those from the anterior subgroup are diffuse reaching many parts of the cortex. Those from the posterior group project to the motor, premotor, and supplemental motor areas. Efferents also reach the striatum. Functions of these nuclei are not known.

The ***midline nuclei*** consist of several small groups of neurons (but there is controversy regarding the groups to be included under this heading). The connections of the nuclei (shown in Figure 12.14) are mainly with the limbic system. Afferents include noradrenergic, serotoninergic, and cholinergic bundles ascending from the brainstem. The midline nuclei probably play a role in memory and arousal.

In the past the intralaminar, midline, and reticular nuclei, grouped together as ***nonspecific thalamic nuclei*** were regarded as part of the ascending reticular activating system, which is responsible for maintaining a state of alertness. They have been described as receiving afferents from the reticular formation (mainly gigantocellular nucleus and ventral reticular nucleus of the medulla; caudal reticular nucleus of pons) and projecting to all parts of the cerebral cortex.

Clinical Correlation

Thalamic syndrome

This occurs due to vascular lesion of the thalamic branch of posterior cerebral artery.

contd...

Characteristic features
- Threshold for appreciation of touch pain or temperature is lowered
- Sensation that is normal may appear to be exaggerated or unpleasant
- There may be spontaneous pain
- Emotions may be abnormal

METATHALAMUS

The metathalamus consists of the medial and lateral geniculate bodies. The medial and lateral geniculate bodies are small oval collections of grey matter situated below the posterior part of the thalamus, lateral to the colliculi of the midbrain (Figure 12.15). Each mass of grey matter is bent on itself, hence the term "***geniculate***". Traditionally, the geniculate bodies have been grouped together under the heading ***metathalamus***, but because of functional relationships, they are now included in the dorsal thalamus.

Medial Geniculate Body

The medial geniculate body is a relay station on the auditory pathway. Medial, ventral, and dorsal nuclei are described within it.

Connections

Afferents

The medial geniculate body receives fibres of the lateral lemniscus either directly or after relay in the inferior colliculus (Figure 12.16). These fibres pass through the brachium of the inferior colliculus. Fibres arising in the medial geniculate body constitute the auditory radiation. The auditory radiation passes through the sublentiform part of the internal capsule to reach the auditory areas of the cerebral cortex.

Each medial geniculate body receives impulses from the cochleae of both sides. It also receives fibres from the auditory area of the cerebral cortex. These fibres form part of the ***descending auditory pathway.***

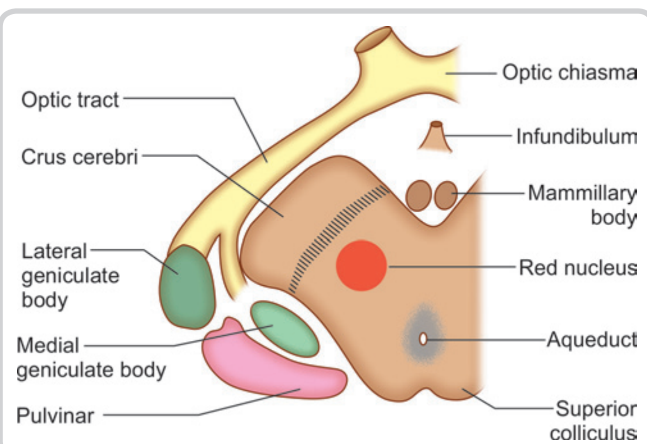

Figure 12.15: Diagram to show the location of medial and lateral geniculate bodies

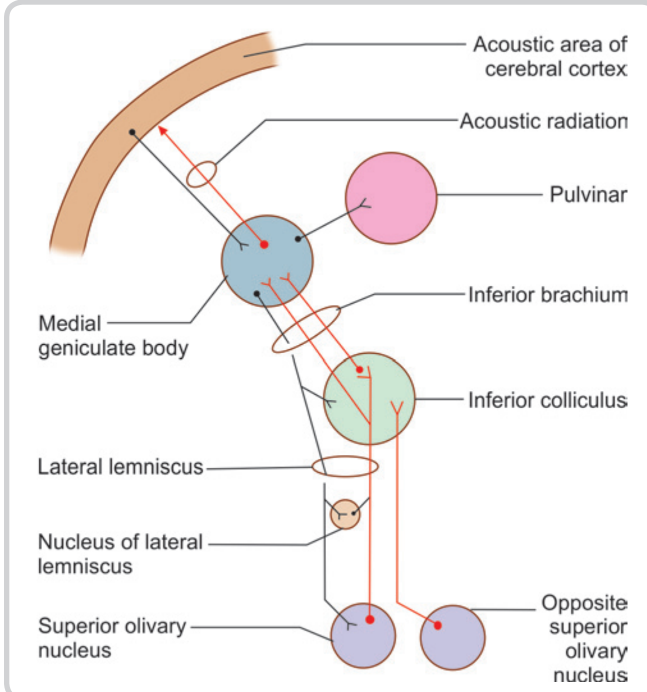

Figure 12.16: Connections of medial geniculate body

Efferents

Different neurons in the ventral nucleus of the medial geniculate body respond to different frequencies of sound (tonotopic organization). The ventral nucleus projects to the primary auditory cortex. The neurons in the dorsal nucleus do not show tonotopic organization. They project to auditory areas around the primary auditory area.

Lateral Geniculate Body

The lateral geniculate body is a relay station on the visual pathway. It is situated on the inferior surface of the pulvinar, anterolateral to the medial geniculate body.

Connections

Afferents

It receives fibres from the retinae of both eyes (Figure 12.17).

Apart from retinal fibres, the lateral geniculate body receives fibres from the primary visual cortex and extrastriate visual areas. It also receives fibres from the superior colliculus and the reticular formation of the pons and medulla.

Noradrenergic fibres reach to it from the locus coeruleus, and serotoninergic fibres from raphe nuclei (midbrain).

Efferents

Efferents arising in this body constitute the optic radiation, which passes through the retrolentiform part of the internal capsule to reach the visual areas of the cerebral cortex.

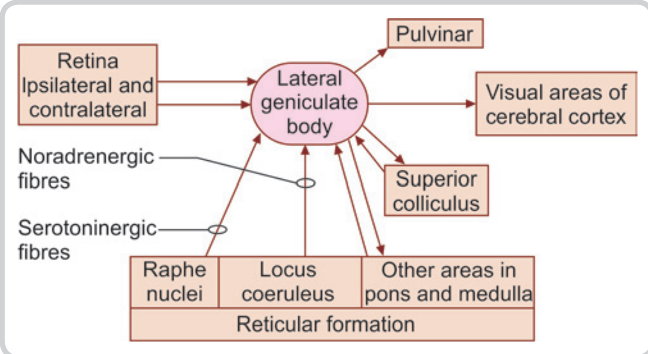

Figure 12.17: Connections of the lateral geniculate body

HYPOTHALAMUS

The hypothalamus is a part of diencephalon—pars ventralis. As its name implies, it lies below the thalamus and separated from it by the hypothalamic sulcus. Most part of hypothalamus is hidden. However, some parts of the hypothalamus can be seen on the external (ventral) surface of the brain. These visible parts of hypothalamus are located in the interpeduncular fossa (Figure 12.18) and form the floor of third ventricle. On the medial side, it forms the lateral wall of the third ventricle below the level of the hypothalamic sulcus.

Boundaries of Hypothalamus

Laterally, it is in contact with the internal capsule, and (in the posterior part) with the ventral thalamus (subthalamus).

Posteriorly, the hypothalamus merges with the ventral thalamus and through it, with the tegmentum of the midbrain.

Anteriorly, it extends up to the lamina terminalis, and merges with certain olfactory structures in the region of the anterior perforated substance.

Inferiorly, the hypothalamus is related to structures in the floor of the third ventricle. These are the tuber cinereum, the infundibulum, and the mammillary bodies, which are considered as parts of the hypothalamus.

Subdivisions of Hypothalamus

For convenience of description the hypothalamus may be subdivided, roughly, into a number of regions. Some authorities divide it (from medial to lateral side) into three ***zones,*** which are as follows:

- ***Periventricular***
- ***Intermediate***
- ***Lateral.***

The periventricular and intermediate zones are often described collectively as the ***medial zone.*** The column of the fornix lies between the medial and lateral zones. The mammillothalamic tract and the fasciculus retroflexus also lie in this plane.

The hypothalamus is also subdivided anteroposteriorly into four ***regions***. These are as follows (Figure 12.19):

- The ***preoptic region*** adjoins the lamina terminalis
- The ***supraoptic (or chiasmatic) region*** lies above the optic chiasma
- The ***tuberal (or infundibulotuberal) region*** includes the infundibulum, the tuber cinereum, and the region above it
- The ***mammillary (or posterior) region*** consists of the mammillary body and the region above it.

The preoptic region differs from the rest of the hypothalamus in being a derivative of the telencephalon. The lamina terminalis also belongs to the telencephalon.

Hypothalamic Nuclei

The entire hypothalamus contains scattered neurons within which some aggregations can be recognized. These aggregations, termed the hypothalamic nuclei, are as follows (Figures 12.20 and 12.21):

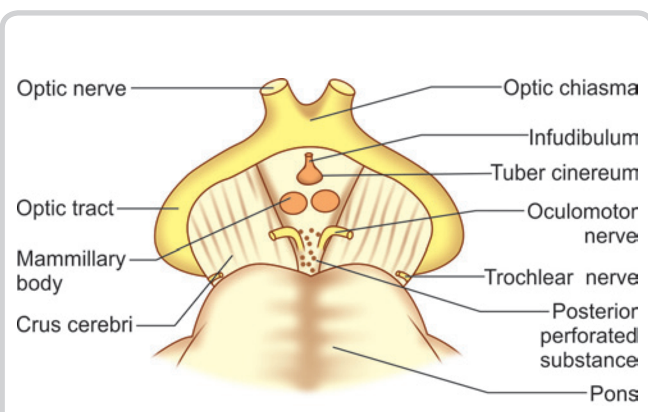

Figure 12.18: Interpeduncular fossa

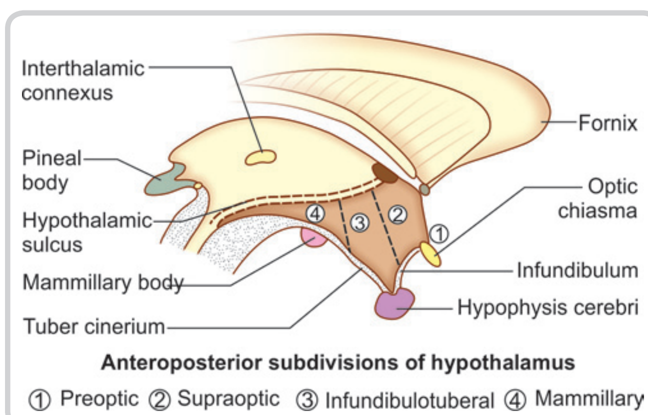

Figure 12.19: Anteroposterior subdivisions of hypothalamus

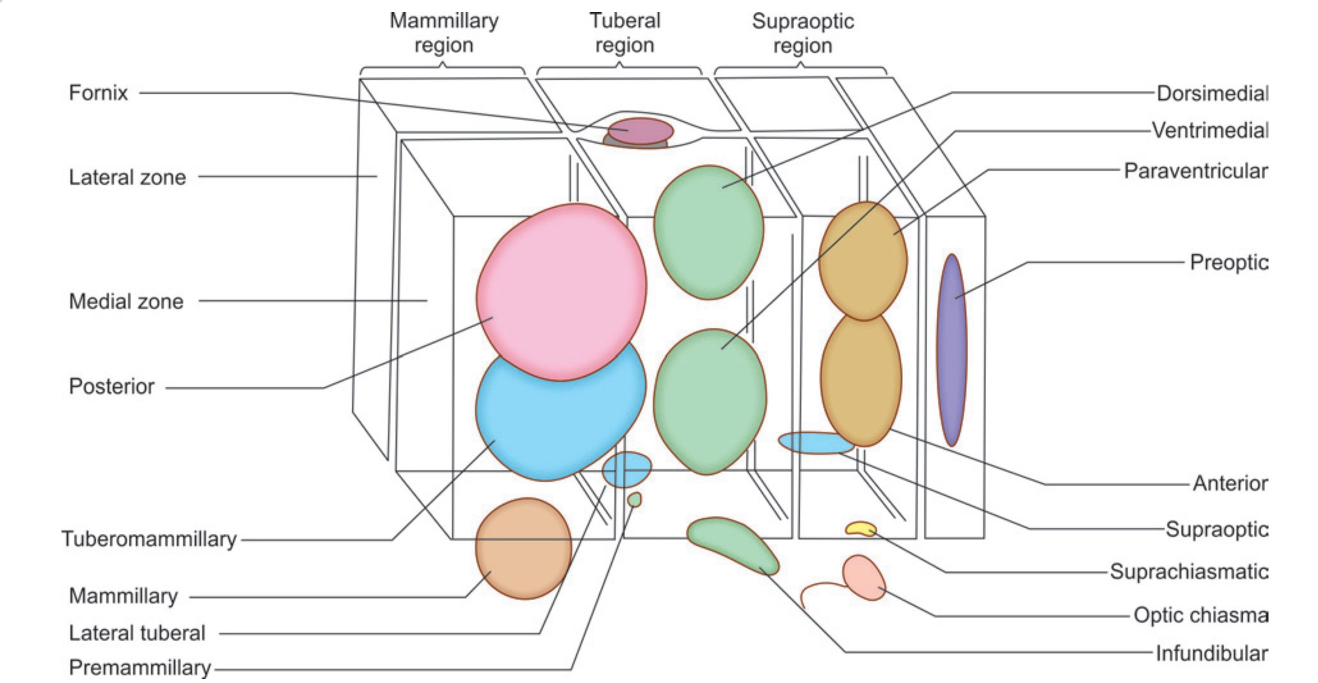

Figure 12.20: Scheme to show the regions and zones of hypothalamus and nuclei within them

Nuclei in the Medial Zone

- The ***preoptic nuclei***
- The ***mammillary nuclei***
- The ***paraventricular nucleus***
- The ***suprachiasmatic nucleus,*** lie in the supraoptic region
- The ***arcuate (or infundibular) nucleus*** lies in the tuberal region
- The ***posterior nucleus*** extends into both the tuberal and mammillary regions
- The ***anterior nucleus*** occupies the supraoptic region
- The ***dorsomedial nucleus***

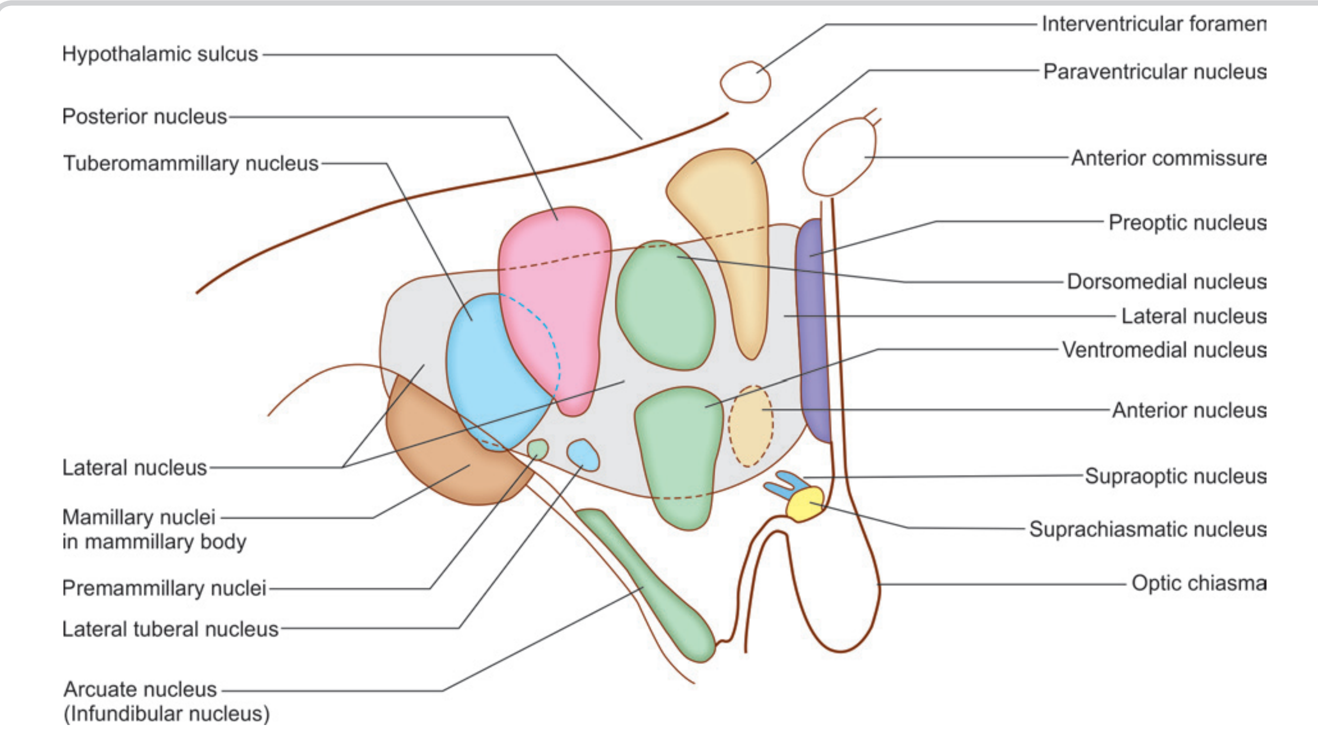

Figure 12.21: Scheme to show main hypothalamic nuclei as seen from the medial (ventricular) aspect

Table 12.3 | Hypothalamic Regions and Nuclei in Them

Region	Nucleus
Preoptic region	Preoptic nucleus
Supraoptic region	• Supraoptic nucleus • Anterior nucleus • Paraventricular nucleus
Tuberal region	• Arcuate (infundibular) nucleus • Ventromedial nucleus • Dorsomedial nucleus
Mammillary region	• Posterior nucleus • Mammillary nuclei

- The ***ventromedial nucleus*** lie in the tuberal part, which also contains small aggregations of cells that constitute
- The ***premammillary nuclei.***

Nuclei in the Lateral Zone

The lateral zone contains a diffuse collection of cells that extend through the supraoptic, tuberal, and mammillary regions. These cells constitute the ***lateral nucleus.*** The lateral zone also contains the following nuclei:

- The ***supraoptic nucleus*** lies in the supraoptic region (just above the optic tract)
- The ***tuberomammillary nucleus*** extends into the tuberal and mammillary regions
- Small aggregations of neurons in the tuberal region constitute the ***lateral tuberal nuclei.***

The nuclei present in different regions of hypothalamus are listed in Table 12.3.

CONNECTIONS OF HYPOTHALAMUS

The hypothalamus is concerned with visceral function and is, therefore, connected to other areas having a similar function. These include the various parts of the limbic system, the reticular formation, and autonomic centres in the brainstem and spinal cord (Figure 12.22). Apart from its neural connections, the hypothalamus also acts by releasing secretions into the bloodstream and cerebrospinal fluid (CSF).

Afferent Connections

- The hypothalamus receives visceral afferents (including those of taste) through the spinal cord and brainstem. The exact pathways are not known. They probably pass through the reticular formation and consist of several relays.

  Many of these fibres pass through a bundle called the ***mammillary peduncle***. Other fibres pass through a bundle called the ***dorsal longitudinal fasciculus***. Fibres from the tegmentum of the midbrain also reach the hypothalamus through the ***medial forebrain bundle***.

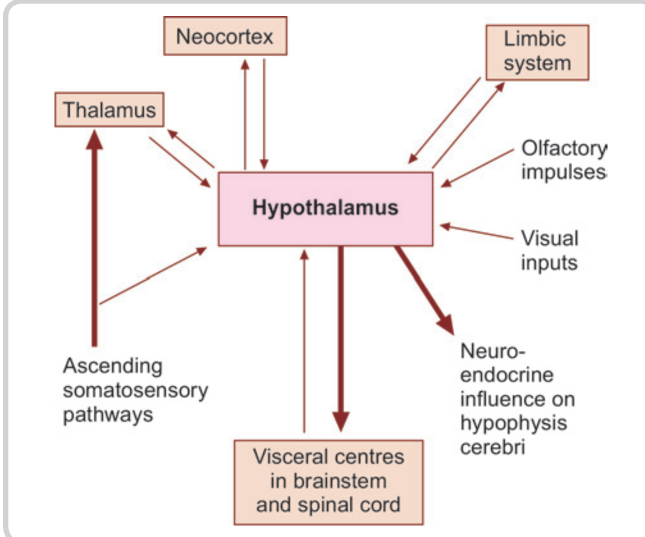

Figure 12.22: Connections of hypothalamus

- Afferents from the nucleus of the solitary tract carry taste impulses (and other visceral sensations)
- Somatic afferents reach the hypothalamus through collaterals of major ascending tracts
- The hypothalamus receives afferents from several centres connected to olfactory pathways and to the limbic system.

  These are the anterior perforated substance, the septal nuclei, the amygdaloid complex, the hippocampus and the piriform cortex. Many of these fibres reach the hypothalamus through the medial forebrain bundle. Fibres from the hippocampus travel through the fornix.
- ***Corticohypothalamic fibres:*** In addition to fibres from the piriform cortex (mentioned above), the hypothalamus is believed to receive fibres from the cortex of the frontal lobe. Some of these are direct. Others relay in the thalamus (medial, dorsal, and midline nuclei) and reach the hypothalamus through periventricular fibres (so called because they travel just subjacent to the ependyma). The gyrus cinguli may influence the hypothalamus indirectly through the hippocampal formation. Some fibres from the orbital cortex may reach the hypothalamus through the medial forebrain bundle.
- The hypothalamus also receives fibres from the subthalamic nucleus and the zona incerta.

Efferent Connections

- The hypothalamus sends fibres to autonomic centres in the brainstem and spinal cord. Centres in the brainstem receiving such fibres include the nucleus of the solitary tract, the dorsal nucleus of the vagus, the nucleus ambiguus, and the parabrachial nucleus. Fibres descending to the spinal cord end in neurons

in the intermediolateral grey column. It also sends fibres to the hippocampal formation, the septal nuclei, the amygdaloid complex, and the tegmentum of the midbrain, and autonomic centres in the brainstem and spinal cord. These fibres pass through the same bundles that convey afferent fibres from these centres.

- Fibres from the mammillary body pass through the mammillothalamic tract to reach the anterior nucleus of the thalamus. New fibres arising here project to the gyrus cinguli. Fibres from the mammillary nuclei also reach the subthalamic region and the tegmentum. (through the mammillotegmental tract).
- Fibres from the hypothalamus project widely to the neocortex. They play a role in maintaining cortical arousal.

The fibre bundles associated with hypothalamus are summarized in Table 12.4.

Control of Hypophysis Cerebri by the Hypothalamus

Neurons in some hypothalamic nuclei produce bioactive peptides that are discharged in the neighbourhood of capillaries or, in some cases, into the cerebrospinal fluid. The process of the production of such bioactive substances by neurons (as distinct from release of neurotransmitters at synapses or efferent nerve endings) is referred to as ***neurosecretion***.

Control of Neurohypophysis

Vasopressin (antidiuretic hormone) and ***oxytocin***, associated with the neurohypophysis, are really neuro-secretory products synthesized in the paraventricular and supraoptic nuclei of the hypothalamus. Axons of the paraventricular nucleus descend towards the supraoptic nucleus as the ***paraventriculohypophyseal tract*** (Figure 12.23). They join axons arising from the supraoptic nucleus to form the ***supraopticohypophyseal tract***. The axons of the tract pass down into the infundibulum and from there into the neurohypophysis. Here, the axons branch profusely and end in relation to capillaries around which they release their secretion.

Control of the Adenohypophysis by the Hypothalamus

The hypothalamus controls secretion of hormones by the adenohypophysis by producing a number of ***releasing factors***. Axons of cells in the infundibular (arcuate) nucleus end in the median eminence and infundibulum, which are closely related to capillaries in the region. The cells of the arcuate (infundibular) nucleus produce releasing factors that travel along their axons and are released into the capillaries. These capillaries carry these factors into the pars anterior of the hypophysis cerebri through the ***hypothalamohypophyseal portal system***. In the pars anterior, these factors are responsible for release of appropriate hormones.

Table 12.4 | Fibre Bundles Associated with Hypothalamus

A/E	Name of the tract	Connects	Functions
Principally afferents	Fornix	Hippocampal formation	Papez circuit for recent memory
	Stria terminalis	Amygdaloid nucleus	Autonomic effect of aggression
	Ventral amygdalofugal pathway	Amygdaloid nucleus	Autonomic effect of aggression
	Mammillary peduncle	Reticular formation of midbrain	Visceral afferent impulses
	Noradrenergic fibres	Locus coeruleus	Circadian rhythm
	Serotoninergic fibres	Raphe nucleus	Circadian rhythm
	Retinohypothalamic fibres	Retina	Circadian rhythm
Afferent + Efferent	Medial forebrain bundle	Anterior olfactory areas, septal areas and tegmentum of the midbrain	Limbic connections to midbrain
Principally efferents	Mammillothalamic tract	Anterior nucleus of the thalamus	Papez circuit for recent memory
	Dorsal longitudinal fasciculus	Central grey matter of brainstem	Projects to parasympathetic nuclei
	Mammillotegmental tract	Tegmental nucleus of the midbrain	Exchange of autonomic information
	Hypothalamospinal tract	Intermediolateral cells of spinal cord	Autonomic connection to T1-L2 and S2-S4
	Paraventriculohypophyseal tract	Neurohypophysis	Release of oxytocin
	Supraopticohypophyseal tract	Neurohypophysis	Release of ADH
	Tuberohypophyseal tract	Adenohypophyseal portal system	Release of GHRH, PIH, TRH, CRH, GnRH

Abbreviations: ADH, antidiuretic hormone; GHRH, growth hormone releasing hormone; PIH, prolactin inhibiting hormone; TRH, thyrotropin releasing hormone; CRH, corticotropin releasing hormone; GnRH, gonadotropin releasing hormone

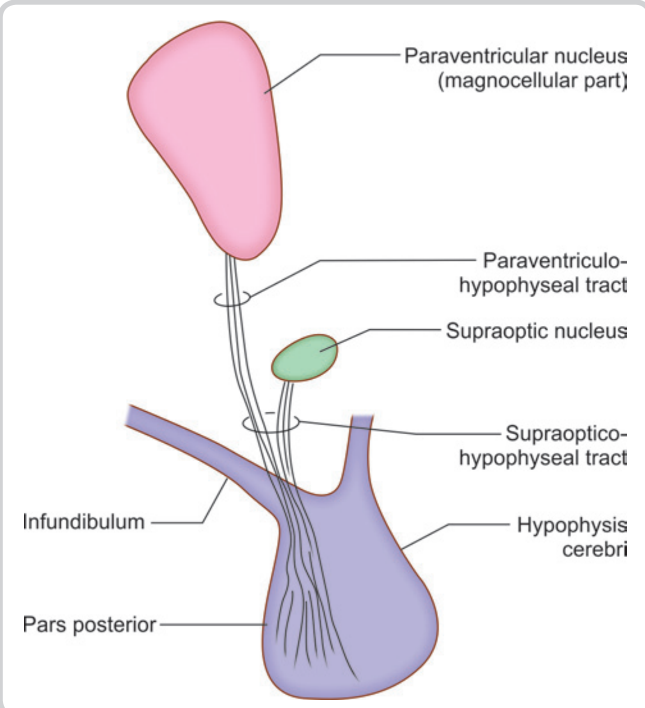

Figure 12.23: Paraventriculohypophyseal and supraoptico-hypophyseal tracts

FUNCTIONS OF HYPOTHALAMUS

The hypothalamus plays an important role in the control of many functions that are vital for the survival of an animal. In exercising such control, the hypothalamus acts in close coordination with higher centres including the limbic system and the prefrontal cortex and with autonomic centres in the brainstem and spinal cord. The main functions attributed to the hypothalamus are as follows:

Regulation of Eating and Drinking Behaviour

The hypothalamus is responsible for feelings of hunger and of satiety, and this determines whether the animal will accept or refuse food. It has been observed that stimulation of the lateral zone of the hypothalamus stimulates hunger, while stimulation of the medial zone produces satiety. The lateral zone is also responsible for thirst and drinking. Based on such studies, a ***feeding centre*** has been described in the lateral hypothalamic nucleus and a ***satiety centre,*** in the ventromedial nucleus.

Regulation of Sexual Activity and Reproduction

The hypothalamus controls sexual activity, both in the male and female. It also exerts an effect on gametogenesis, on ovarian and uterine cycles, and on the development of secondary sexual characters. These effects are produced by influencing the secretion of gonadotropic hormones by the hypophysis cerebri. Liberation of gonadotropin releasing hormone (GnRH) follows a monthly cyclical pattern in females while, in males, it exhibits a completely different pattern of secretion in the form of spikes. The ***sexually dimorphic nucleus*** is a cluster of cells located in the preoptic area of hypothalamus of the brain that is believed to be related to sexual behaviour in animals. The volume of nucleus is significantly larger (about twice) in males than in females, caused, by both, a greater cell number and larger cell size.

Control of Autonomic Activity

The hypothalamus exerts an important influence on the activity of the autonomic nervous system and, thus, has considerable effect on cardiovascular, respiratory, and alimentary functions. Sympathetic activity is said to be controlled predominantly by caudal parts of the hypothalamus and parasympathetic activity, by cranial parts.

Emotional Behaviour

The hypothalamus has an important influence on emotions like fear, anger, and pleasure. Stimulation of lateral areas of the hypothalamus produces sensations of pleasure, while stimulation of medial areas produces pain or other unpleasant effects.

Control of Endocrine Activity

The influence of the hypothalamus in the production of hormones by the pars anterior of the hypophysis cerebri and the elaboration of oxytocin and the antidiuretic hormone by the hypothalamus itself have been described above. Through control of the adenohypophysis, the hypothalamus indirectly influences the thyroid gland, the adrenal cortex, and the gonads.

Response to Stress

Through control over the autonomic nervous system and hormones, the hypothalamus plays a complex role in the way a person responds to stress.

Temperature Regulation

Some neurons in the preoptic nucleus of the hypothalamus act as a thermostat to control body temperature. When body temperature rises or falls, appropriate mechanisms are brought into play to bring the temperature back to normal.

Rostral hypothalamus acts as anti-rise centre and caudal, as anti-fall centre.

Biological Clock

Several functions of the body show a cyclic variation in activity over the twenty four hours of a day. The most conspicuous of these is the cycle of sleep and waking. Such cycle (called ***circadian rhythms***) are believed to be

Table 12.5 | Clinical Correlation

Nucleus	Function	Lesions
Preoptic nucleus	Sexually dimorphic	Irregular menstrual cycle and loss of libido
Anterior nucleus	Heat-loss centre	Hyperthermia
Posterior	Heat-rise centre	Hypothermia
Lateral	Hunger centre	Anorexia and emaciation
Medial	Satiety centre	Obesity
Mammillary body	Recent memory	Wernicke's encephalopathy
Supraoptic nucleus	ADH secretion	Diabetes insipidus

Abbreviations: ADH, antidiuretic hormone

controlled by the hypothalamus, which is said to function as a biological clock. The suprachiasmatic nucleus is believed to play an important role in this regard. Lesions of the hypothalamus disturb the sleep-waking cycle.

The clinical correlation of hypothalamus is given in Table 12.5.

EPITHALAMUS

The epithalamus lies in relation to the posterior part of the roof of the third ventricle and in the adjoining part of its lateral wall. The structures included in the epithalamus are as follows:

- Pineal body
- Habenular nuclei—medial and lateral
- Stria medullaris thalami (stria habenularis) and habenular commissure
- Posterior commissure

Pineal body (Epiphysis Cerebri)

The pineal body (or pineal gland) is a small piriform structure present in relation to the posterior wall of the third ventricle of the brain (Figure 12.24). It has for long been regarded as a vestigeal structure of no functional importance. However, it is now known to be an endocrine gland of considerable significance. The pineal body is made up of cells called ***pinealocytes.*** Pinealocytes are separated from one another by neuroglial cells that resemble astrocytes in structure.

The attachment of the pineal body to the posterior wall of the third ventricle is through a stalk that has two laminae: superior and inferior. The superior lamina is traversed by fibres of the ***habenular commissure*** and the inferior lamina, by fibres of the ***posterior commissure.***

The pineal body is innervated by postganglionic sympathetic neurons located in the superior cervical sympathetic ganglia. The fibres travel through the ***nervus conarii***. The fibres of this nerve end in the habenular nuclei. Fibres arising in these nuclei form the ***habenulopineal tract.*** A ganglion (***ganglion conarii)*** has been described at the apex of the pineal body.

Function

The pineal body produces a number of hormones (chemically indolamines or polypeptides). These hormones have an important regulatory influence on many endocrine organs, including the hypophysis cerebri, the thyroid, the parathyroids, the adrenals, and the gonads. The hormones of the pineal body reach the hypophysis cerebri both through blood and through the cerebrospinal fluid.

Some activities of the pineal body (for example, the secretion of the hormone ***melatonin***) show a marked circadian rythm, which appears to be strongly influenced by exposure of the animal to light. Activity of the pineal body is greater in darkness. It has been suggested that the suprachiasmatic nucleus of the hypothalamus plays an important role in the cyclic activity of the pineal body. This nucleus receives fibres from the retina. In turn, it projects to the tegmental reticular nuclei. Reticulospinal fibres arising in these nuclei influence the sympathetic preganglionic

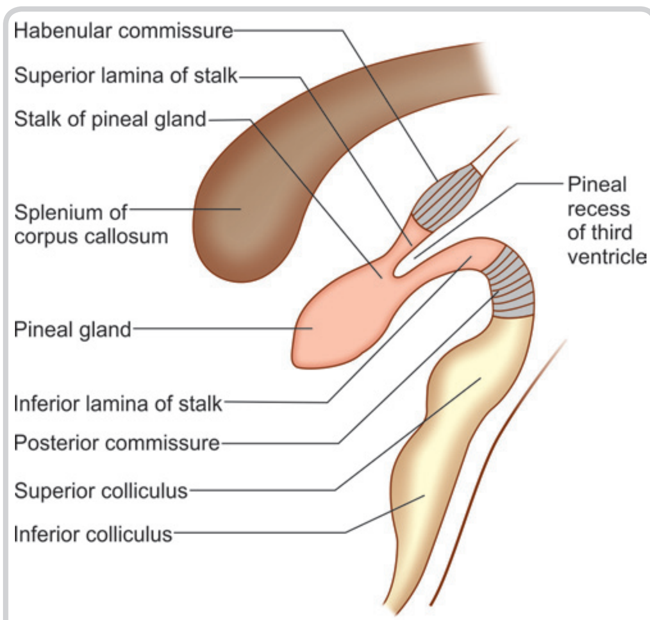

Figure 12.24: The pineal body (gland)

neurons in the first thoracic segment of the the spinal cord. Axons of these neurons reach the superior cervical sympathetic ganglia from which the ***nervus conarii*** arises and supplies the pineal body.

Clinical Correlation

A tumour of the pineal body can produce ***precocious puberty***. Melatonin is believed to regulate the onset of puberty.

Habenular Nuclei

The habenular nuclei (medial and lateral) are situated in relation to a triangular depression in the wall of the third ventricle called the ***habenular trigone.*** The trigone lies in relation to the dorsomedial part of the thalamus. It is medial to the pulvinar, separated from it by the sulcus habenulae. The superior colliculus lies just behind and below the trigone. The habenular nuclei of the two sides are connected by fibres that form the habenular commissure (see below).

These nuclei have been regarded as cell stations in olfactory and visceral pathways, but their function is not understood. The habenular nuclei receive afferents from several areas included in the limbic system (Figure 12.25). Most of these fibres travel through the stria medullaris thalami (see below). Ascending fibres from the tegmentum of the midbrain reach the habenular nuclei through ascending noradrenergic and serotonergic bundles that travel through the habenulopeduncular tract (see below).

Efferents from the habenular nuclei reach the pineal body through the ***habenulopineal tract***. The main outflow from these nuclei reaches the interpeduncular nucleus through the ***habenulopeduncular tract,*** which is also called the ***fasciculus retroflexus.*** Other efferents are shown in Figure 12.25. The habenular nuclei influence neurons concerned with various visceral and endocrine functions. They may be involved in control of sleep and in temperature regulation.

Stria Medullaris Thalami (Stria Habenularis) and Habenular Commissure

The ***stria medullaris thalami*** is a bundle of fibres lying deep to the taenia thalami (along the junction of the medial and superior surfaces of the thalamus). It begins near the anterior pole of the thalamus and runs backwards to reach the habenular region. Many afferents to the habenular nuclei pass through the stria medullaris thalami.

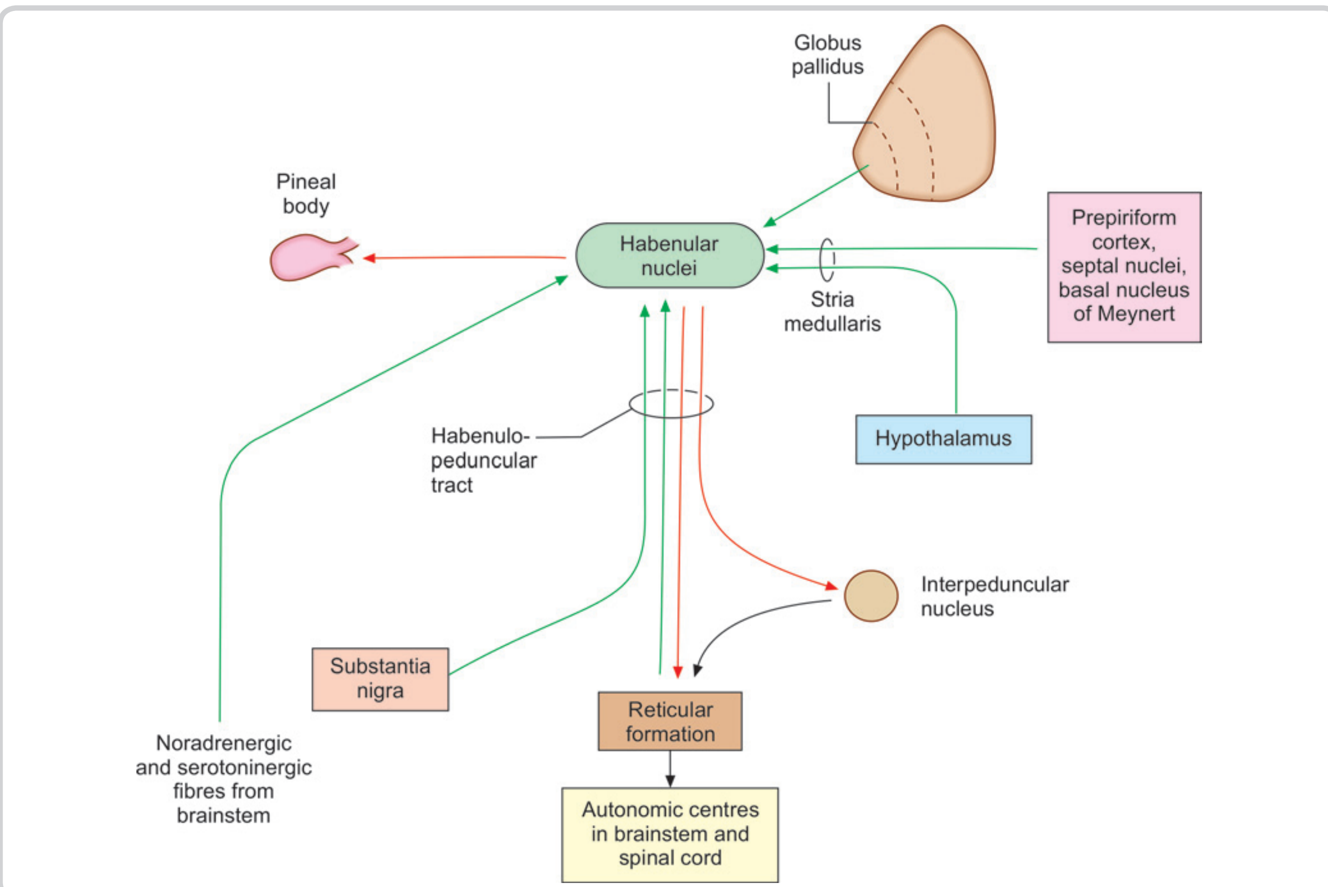

Figure 12.25: Connections of habenular nuclei

Some fibres of the stria medullaris thalami cross in the superior (or anterior) lamina of the pineal stalk to reach the habenular nuclei of the opposite side. These fibres constitute the ***habenular commissure.***

Several neuromediators have been demonstrated in the fibres of the stria medullaris. These include acetylcholine, noradrenaline, serotonin, and gamma-aminobutyric acid (GABA).

Posterior Commissure

The posterior commissure lies in the inferior lamina of the stalk of the pineal body. A number of small nuclei are present in relation to the commissure. These include the interstitial and dorsal nuclei of the posterior commissure, the nucleus of Darkschewitsch, and the interstitial nucleus of Cajal. Some fibres arising from these nuclei pass through the posterior commissure. Other fibres continue into it from the medial longitudinal bundle. Some fibres arising in the thalamus, the tectum, and the pretectal nuclei also pass through the posterior commissure.

VENTRAL THALAMUS

The part of the diencephalon that is called the ventral thalamus lies below the posterior part of the thalamus, behind and lateral to the hypothalamus.

Inferiorly, the ventral thalamus is continuous with the tegmentum of the midbrain. Laterally, it is related to the lowest part of the internal capsule.

The main masses of grey matter that are included in the ventral thalamus are the reticular nucleus (previously described as part of the dorsal thalamus) and the zona incerta.

Reticular Nucleus

The reticular nucleus is made up of a thin layer of neurons covering the lateral aspect of the (dorsal) thalamus, separated from the latter by the external medullary velum. Laterally, the nucleus is related to the internal capsule. Inferiorly, it becomes partially continuous with the zona incerta.

Most fibres emerging from the dorsal thalamus have to traverse the reticular nucleus (The fibres crossing through it give the nucleus a reticulated appearance, and hence, the name). As they pass through it, the fibres give collaterals to the reticular nucleus.

In this way, the nucleus receives somatic, visceral, and auditory impulses. The main efferents of the reticular nucleus pass back into the dorsal thalamus. These fibres are GABAergic. They may influence conduction through the dorsal thalamus (Figure 12.26). The reticular nucleus also receives fibres from the nucleus cuneiformis (in the reticular formation of the midbrain).

Zona Incerta

The zona incerta is a thin lamina of grey matter continuous with the reticular nucleus of the thalamus. It intervenes between the subthalamic nucleus and the thalamus. Its functions are not known. Some of its connections are shown in Figure 12.27.

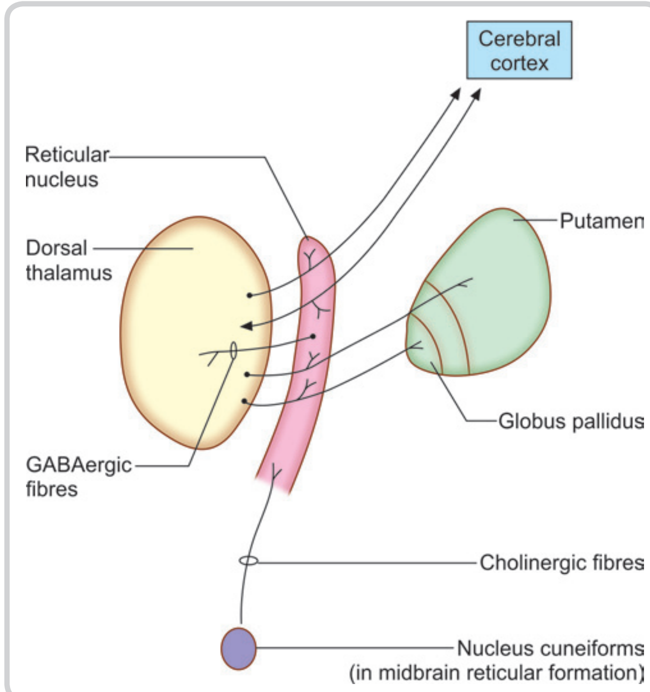

Figure 12.26: Connections of reticular nucleus of the thalamus

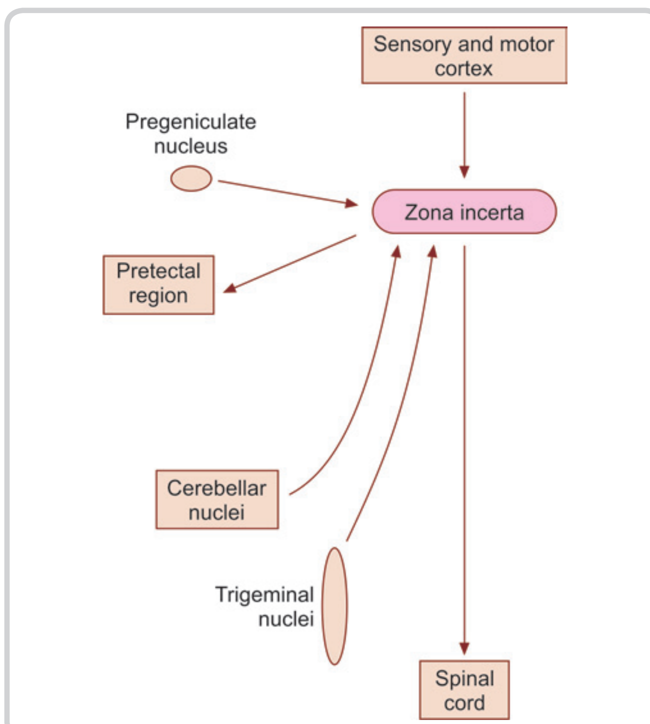

Figure 12.27: Connections of zona incerta

Lying near the zona incerta, there are two groups of neurons that need mention:

- Some neurons lie along the lower edge of the zona incerta (near the upper end of the red nucleus). These are termed the nuclei of the prerubral field.
- Some neurons lying within the fibres of the ansa lenticularis constitute the entopeduncular nucleus.

Both these nuclei receive fibres from the globus pallidus and relay them to the reticular formation of the midbrain. Some fibres descend to the inferior olivary complex and to other brainstem nuclei.

Fibre Bundles Passing Through Subthalamic Region

In addition to its grey matter, the subthalamic region contains a number of fibre bundles (Figure 12.28). Ascending tracts (medial lemniscus, spinal lemniscus, trigeminal lemniscus) pass through it on their way from the midbrain to the thalamus. They are accompanied by dentatothalamic and rubrothalamic fibres.

The subthalamic region also contains two bundles of fibres that connect the globus pallidus to the thalamus. These are the ***ansa lenticularis*** and the ***fasciculus lenticularis***. Associated with these bundles, there are certain regions called the fields of Forel (H, H1, and H2) as shown in Figure 12.28.

Starting from the globus pallidus, the ***ansa lenticularis*** winds round the ventral and posterior border of the internal capsule to reach the subthalamic region, where it lies ventral and medial to the subthalamic nucleus. Fibres of the ***fasciculus lenticularis*** intersect those of the internal capsule to reach the subthalamic region. Here, they pass medially above the subthalamic nucleus and below the zona incerta. This region is field H2 of Forel.

The ***subthalamic fasciculus*** (connecting the globus pallidus to the subthalamic nucleus) occupies a position intermediate between the ansa lenticularis and the fasciculus lenticularis. The fibres of the ansa lenticularis and of the fasciculus lenticularis join together medial to the subthalamic nucleus (in field H of Forel) to form the ***thalamic fasciculus*** (which is also joined by dentatothalamic and rubrothalamic fibres). The thalamic fasciculus passes above the zona incerta (field H1 of Forel) to reach the thalamus.

Subthalamic Nucleus (of Luys)

As explained above the subthalamic nucleus, which has traditionally been described as a part of the subthalamic

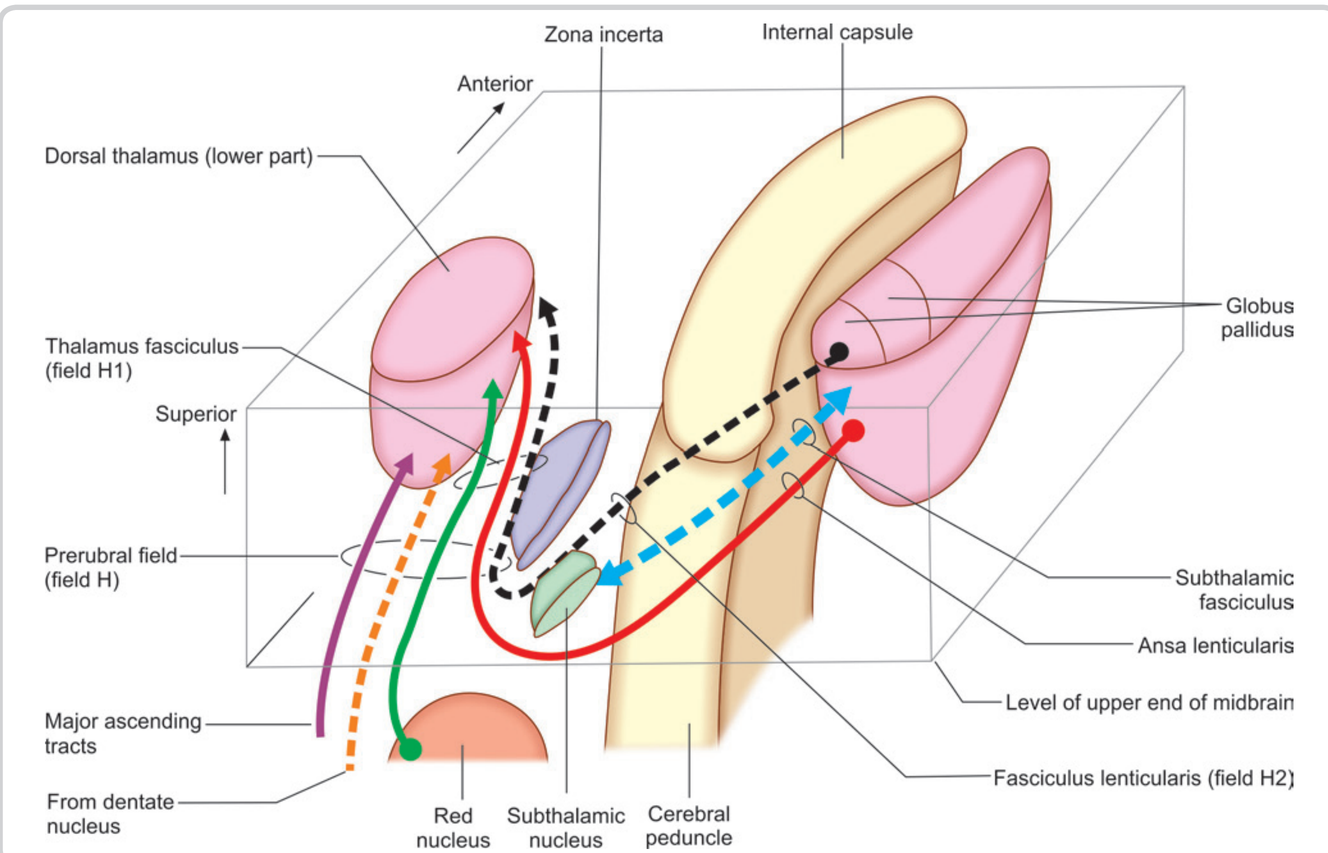

Figure 12.28: Schematic 3-dimensional diagram of ventral thalamic region to show some of its features

region is now grouped functionally with the basal nuclei/ganglia.

ARTERIAL SUPPLY OF DIENCEPHALON

The thalamus is supplied mainly by perforating branches of the posterior cerebral artery. The posteromedial group of branches (also called thalamoperforating arteries) supply the medial and anterior part. The posterolateral group (also called thalamo-geniculate branches) supply the posterior and lateral parts of the thalamus. The thalamus also receives some branches from the posterior communicating, anterior choroidal, posterior choroidal, and middle cerebral arteries.

The anterior part of ***the hypothalamus*** is supplied by central branches of the anteromedial group (arising from the anterior cerebral artery). The posterior part is supplied by central branches of the posteromedial group (arising from the posterior cerebral and posterior communicating arteries).

Multiple Choice Questions

1. Which of the following nuclei is functionally a part of basal nuclei?
   A. Dorsal thalamus
   B. Epithalamus
   C. Metathalamus
   D. Subthalamus

2. The lateral surface of the thalamus is related to
   A. Globus pallidus
   B. Head of the caudate nucleus
   C. Posterior limb of internal capsule
   D. Third ventricle

3. The sheet of white matter that divides the thalamus into different groups of nuclei is known as
   A. Internal medullary lamina
   B. Lamina terminalis
   C. Stratum zonale
   D. Stria medullaris thalami

4. The medial group of thalamic nuclei is concerned with
   A. Emotional aspect of the behaviour
   B. Receiving somatosensory impulses
   C. Recent memory
   D. Relay station from corpus striatum

5. Which of the following thalamic peduncles passes through the posterior limb of the internal capsule?
   A. Anterior
   B. Inferior
   C. Posterior
   D. Superior

6. Which of the following is the most posterior part of the hypothalamus?
   A. Infundibulum
   B. Lamina terminalis
   C. Mammillary bodies
   D. Tuber cinereum

7. Which of the following group of nuclei of the hypothalamus secretes the hormones of neurohypophysis?
   A. Arcuate and tuberomammillary
   B. Mammillary and suprachiasmatic
   C. Preoptic and infundibular
   D. Supraoptic and paraventrivular

8. The centre located at the lateral part of hypothalamus regulates
   A. Autonomic activity
   B. Hunger and thirst
   C. Sexual activity
   D. Temperature

9. Which sensory pathway reaches cerebral cortex by-passing thalamus?
   A. Auditory
   B. Gustatory
   C. Olfactory
   D. Visual

10. Nervus conarii supplying pineal gland arises from
   A. Nucleus of reticular formation
   B. Preganglionic fibres from vagus nerve
   C. Superior cervical sympathetic ganglion
   D. Suprachiasmatic nucleus

Answers

1. D **2.** C **3.** A **4.** A **5.** D **6.** C **7.** D **8.** B **9.** C **10.** C

Chapter 13

Cerebral Hemispheres – External Features

Specific Learning Objectives

At the end of learning, the student shall be able to:
- Describe the borders, surfaces and poles of cerebral hemisphere
- Describe the sulci and gyri on each surface of cerebral hemisphere
- Define the lobes of cerebrum
- Describe the layers of cerebral cortex and the types of cells in them
- Define the functional areas of cerebrum including their Brodmann numerals
- Describe the arterial supply of cerebral cortex
- Describe relevant clinical anatomy

INTRODUCTION

The cerebrum is the largest part of the brain. It has an ovoid shape. It consists of two incompletely separated cerebral hemispheres (Figure 13.1). The outer surface of the cerebral hemisphere is covered with cortex, which is highly folded due to the presence of sulci and gyri.

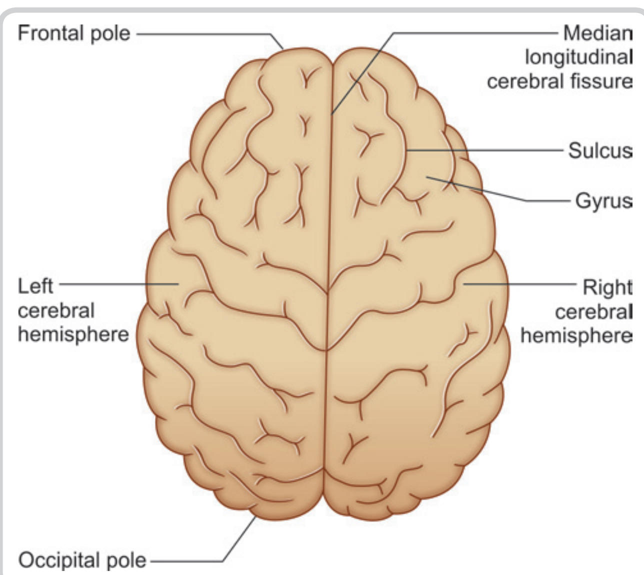

Figure 13.1: Superior view of the cerebrum

The core of the hemisphere consists of white matter containing a group of nuclei called basal ganglia. The cavity inside each hemisphere is called the lateral ventricle.

The median longitudinal fissure of cerebrum intervenes between the medial surfaces of the right and left hemispheres. At the bottom of the fissure lies the corpus callosum, which is a connecting bond between the two hemispheres. The contents of the longitudinal fissure are falx cerebri and the accompanying arachnoid mater, pia mater covering the medial surfaces of the hemispheres, anterior cerebral vessels, and the indusium griseum on the superior surface of the corpus callosum.

The surface of the cerebral hemisphere is covered by a thin layer of grey matter called the ***cerebral cortex***. The cortex follows the irregular contour of the sulci and gyri of the hemisphere and extends into the depths of the sulci. As a result of this folding of the cerebral surface, the cerebral cortex acquires a much larger surface area than the size of the hemispheres would otherwise allow.

The greater part of the cerebral hemisphere deep to the cortex is occupied by white matter, within which are embedded certain important masses of grey matter. Immediately lateral to the third ventricle, there are the ***thalamus*** and ***hypothalamus*** (and certain smaller masses) derived from the diencephalon. More laterally, there is the ***corpus striatum,*** which is derived from the telencephalon. It consists of two masses of grey matter, the ***caudate nucleus*** and the ***lentiform nucleus,*** which consists of two functionally distinct parts, the putamen and the globus pallidus (Figure 13.2). A little lateral to the lentiform nucleus, is the cerebral cortex in the region of the insula. Between the lentiform nucleus and the insula, there is a thin layer of grey matter called the ***claustrum.*** The caudate nucleus, the lentiform nucleus, the claustrum, and some other masses of grey matter (all of telencephalic origin) are referred to as ***basal nuclei*** or ***basal ganglia.***

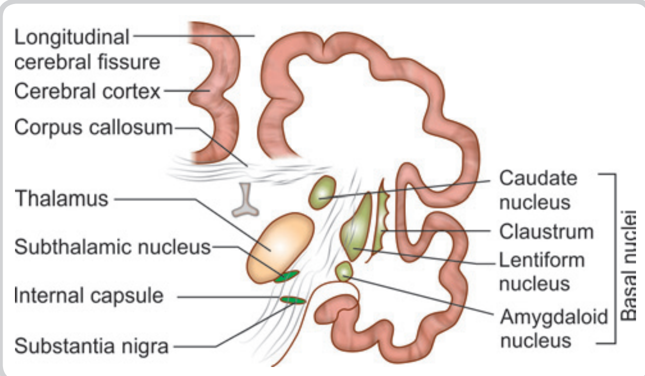

Figure 13.2: Coronal hemisection of cerebrum showing the caudate and the lentiform nucleus, which consists of two functionally distinct parts, the putamen and the globus pallidus

Borders

A coronal section through the cerebral hemispheres (Figure 13.4) shows that each hemisphere has three borders: ***superomedial, inferolateral,*** and ***inferomedial.***

The inferomedial border is divided into an anterior part called the ***medial orbital border*** and a posterior part called the ***medial occipital border***. The orbital part of the inferolateral border is called the ***superciliary border*** (as it lies just above the level of the eyebrows).

Sulci and Gyri

The surfaces of the cerebral hemisphere are not smooth. They show a series of grooves or ***sulci*** (Figure 13.1), which are separated by intervening areas that are called ***gyri***.

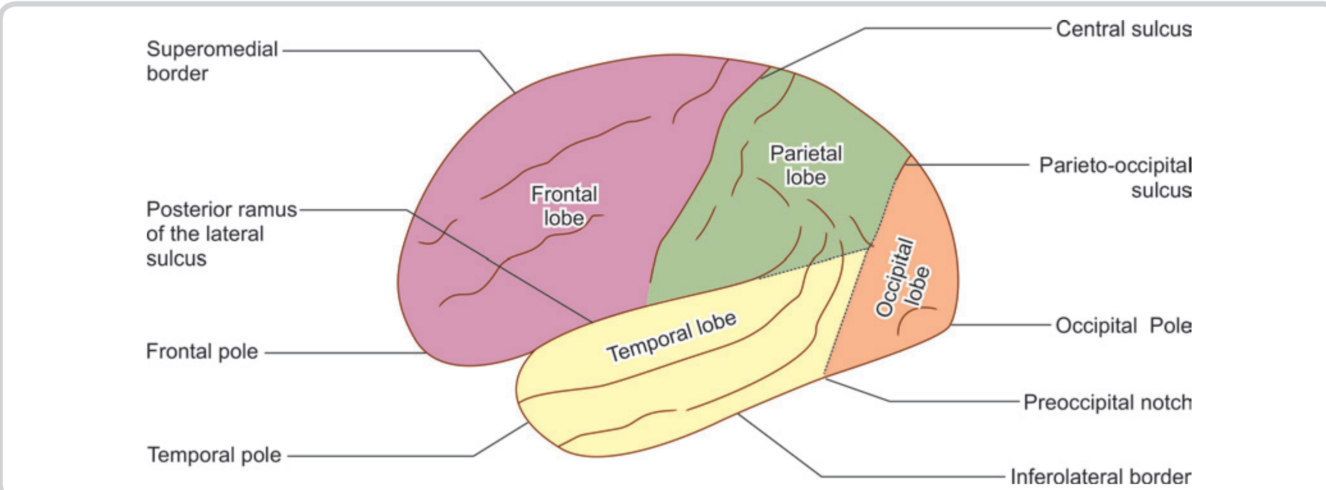

Figure 13.3: Lateral aspect of the cerebral hemisphere to show borders, poles, and lobes

EXTERNAL FEATURES OF CEREBRAL HEMISPHERES

The cerebral hemisphere has three poles, three surfaces, and three borders.

Poles

When viewed from the lateral aspect, each cerebral hemisphere has the appearance shown in Figure 13.3. Three somewhat pointed ends or poles can be recognized. These are the frontal pole anteriorly, the occipital pole posteriorly, and the temporal pole that lies between the frontal and occipital poles and points forwards and somewhat downwards.

Surfaces

Each cerebral hemisphere has three surfaces—superolateral, medial (or vertical), and inferior (Figure 13.4). The right and left medial surfaces enclose the longitudinal fissure. The inferior surface is subdivided into orbital and tentorial surfaces by the stem of the lateral sulcus (Figure 13.5).

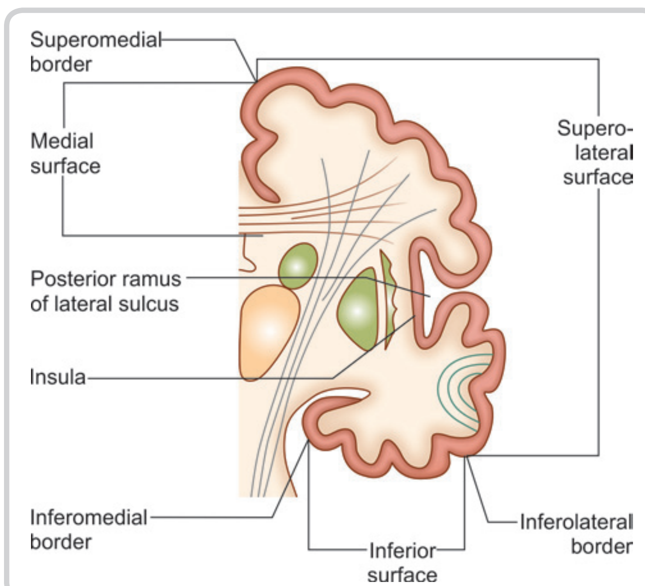

Figure 13.4: Coronal section through a cerebral hemisphere to show its borders and surfaces

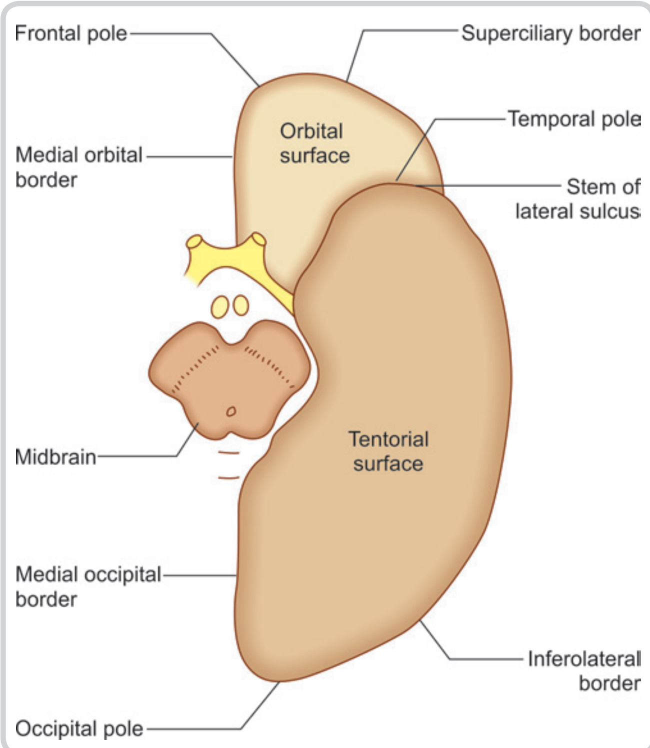

Figure 13.5: Inferior aspect of a cerebral hemisphere to show its borders, poles, and surfaces

- On the superolateral surface of the hemisphere, there are two prominent sulci (Figures 13.6A and B). One of these is the ***posterior ramus of the lateral sulcus,*** which begins near the temporal pole and runs backwards and slightly upwards. Its posteriormost part curves sharply upwards. The second sulcus that is used to delimit the lobes is the ***central sulcus.*** It begins on the superomedial margin, a little behind the midpoint between the frontal and occipital poles and runs downwards and forwards to end a little above the posterior ramus of the lateral sulcus
- On the medial surface of the hemisphere, near the occipital pole, there is a sulcus called the ***parieto-occipital sulcus*** (Figure 13.6). The upper end of this sulcus reaches the superomedial border and a small part of it can be seen on the superolateral surface (Figure 13.3).
- A little anterior to the occipital pole, the inferolateral border shows a slight indentation called the ***preoccipital notch (or preoccipital incisure)***.

Lobes

There are four lobes, namely frontal, parietal, occipital, and temporal, which are well demarcated on the superolateral surface (Figure 13.3).

To define the limits of various lobes, two imaginary lines are drawn. The first imaginary line connects the upper end of the parieto-occipital sulcus to the preoccipital notch. The second imaginary line is a backward continuation of the posterior ramus of the lateral sulcus (excluding the posterior upturned part) to meet the first line. The limits of the various lobes are as follows:

- The ***frontal lobe*** lies anterior to the central sulcus and above the posterior ramus of the lateral sulcus.
- The ***parietal lobe*** lies behind the central sulcus. It is bounded below by the posterior ramus of the lateral sulcus and by the second imaginary line and behind by the upper part of the first imaginary line.
- The ***occipital lobe*** is the area lying behind the first imaginary line.
- The ***temporal lobe*** lies below the posterior ramus of the lateral sulcus and the second imaginary line. It is separated from the occipital lobe by the lower part of the first imaginary line.
- The ***insula or insular lobe (island of Reil)*** is an area of the cortex that lies at the bottom of the lateral sulcus and hence hidden from the surface view.
- The ***limbic lobe*** is a part of limbic system, forming a border between telencephalic and diencephalic structures and comprising of subcallosal, cingular and parahippocampal gyri. The limbic lobe is seen on the medial and inferior surface of the cerebral hemisphere.

Before going on to consider further subdivisions of each of the lobes named above, attention has to be directed to details of some structures already mentioned.

- The upper end of the central sulcus winds round the superomedial border to reach the medial surface. Here its end is surrounded by a gyrus called the ***paracentral lobule*** (Figure 13.8). The lower end of the central sulcus is always separated by a small interval from the posterior ramus of the lateral sulcus (Figure 13.3).
- The lateral sulcus begins on the inferior aspect of the cerebral hemisphere, where it lies between the orbital surface and the anterior part of the temporal lobe (Figures 13.6 and 13.10). It runs laterally to reach the superolateral surface. On reaching this surface, it divides into three rami (branches). These rami are ***anterior (or anterior horizontal), ascending (or anterior ascending),*** and ***posterior*** (Figure 13.6). The anterior and ascending rami are short and run into the frontal lobe in the directions indicated by their names. The posterior ramus has already been considered. Unlike most other sulci, the lateral sulcus is very deep. Its walls cover a fairly large area of the surface of the hemisphere called the ***insula*** (Figure 13.7).

SUPEROLATERAL SURFACE OF CEREBRAL HEMISPHERE

The subdivisions of the superolateral surface are described below and are shown in Figure 13.6A.

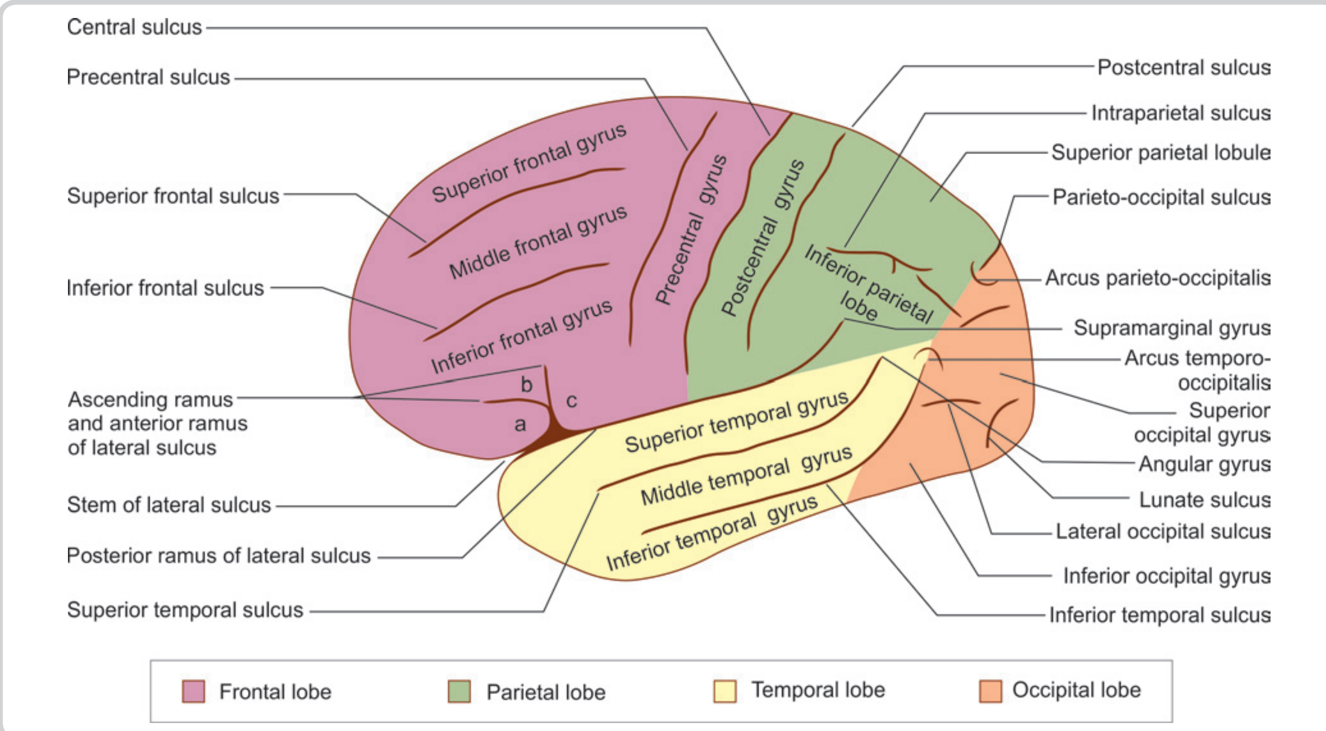

Figure 13.6A: Simplified presentation of sulci and gyri on the superolateral surface of the cerebral hemisphere. (a = pars orbitalis; b = pars triangularis; c = pars opercularis)

Figure 13.6B: Superolateral surface seen in a brain specimen

Frontal Lobe

The frontal lobe is further subdivided as follows. The ***precentral sulcus*** runs downwards and forwards parallel to and a little anterior to the central sulcus. The area between it and the central sulcus is the ***precentral gyrus.*** In the region anterior to the precentral gyrus there are two sulci that run in an anteroposterior direction. These are the ***superior*** and ***inferior frontal sulci.*** They divide this region into ***superior***, ***middle,*** and ***inferior frontal gyri.*** The anterior and ascending rami of the lateral sulcus extend into the inferior frontal gyrus, dividing it into three parts: The part below the anterior ramus is the ***pars orbitalis***, that between the anterior and ascending rami is the ***pars triangularis***; and the part posterior to the ascending ramus is the ***pars opercularis.***

Temporal Lobe

The temporal lobe has two sulci that run parallel to the posterior ramus of the lateral sulcus. They are termed the ***superior and inferior temporal sulci.*** They divide the superolateral surface of this lobe into ***superior, middle, and inferior temporal gyri.***

Parietal Lobe

The parietal lobe shows the following subdivisions. The ***postcentral sulcus*** runs downwards and forwards parallel to and a little behind the central sulcus. The area between these two sulci is the ***postcentral gyrus.*** The rest of the parietal lobe is divided into a ***superior parietal lobule*** and an ***inferior parietal lobule*** by the ***intraparietal sulcus.*** The upturned posterior end of the posterior ramus of the lateral sulcus extends into the inferior parietal lobule. The posterior ends of the superior and inferior temporal sulci also turn upwards to enter this lobule. The upturned ends of these three sulci divide the inferior parietal lobule into three parts. The part that arches over the upturned posterior end of the posterior ramus of the lateral sulcus is called the ***supramarginal gyrus.*** The part that arches over the superior temporal sulcus is called the ***angular gyrus.*** The part that arches over the posterior end of the inferior temporal sulcus is called the ***arcus temporo-occipitalis.***

Occipital Lobe

The occipital lobe shows three rather short sulci. One of these, the ***lateral occipital sulcus*** lies horizontally and divides the lobe into ***superior and inferior occipital gyri.*** The ***lunate sulcus*** runs downwards and slightly forwards just in front of the occipital pole. The vertical strip just in front of it is the ***gyrus descendens.*** The ***transverse occipital sulcus*** is located in the uppermost part of the occipital lobe. The upper end of the parieto-occipital sulcus (which just reaches the superolateral surface from the medial surface) is surrounded by the ***arcus parieto-occipitalis.*** As its name suggests, it belongs partly to the parietal lobe and partly to the occipital lobe.

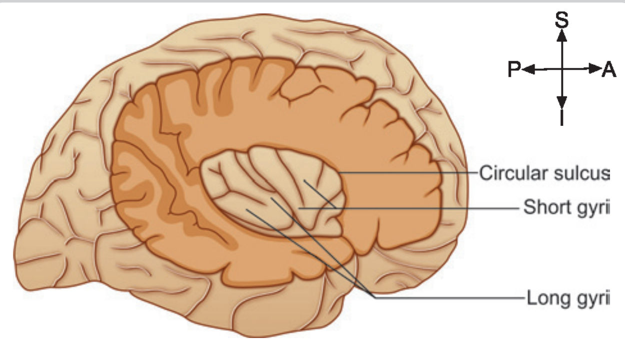

Figure 13.7: The insula of the cerebrum exposed

Insula

In the depth of the stem and posterior ramus of the lateral sulcus, there is a part of the cerebral hemisphere called the ***insula*** (*insula = hidden*) (Figure 13.7). It is surrounded by a ***circular sulcus***. During development of the cerebral hemisphere, this area grows less than surrounding areas, which therefore, come to overlap it and occlude it from surface view. These surrounding areas are called ***opercula*** (= lids). The ***frontal operculum*** lies between the anterior and ascending rami of the lateral sulcus. The ***frontoparietal operculum*** lies above the posterior ramus of the lateral sulcus. The ***temporal operculum*** lies below this sulcus. The temporal operculum has a superior surface hidden in the depth of the lateral sulcus. On this surface are located two gyri called the ***anterior and posterior transverse temporal gyri***. The surface of the insula itself is divided into a number of gyri.

MEDIAL SURFACE OF CEREBRAL HEMISPHERE

The features of the medial surface include the sulci and gyri, as well as the corpus callosum and the midline structures below it (Figure 13.8).

The ***corpus callosum*** is a prominent arched structure consisting of commissural fibres passing from one hemisphere to the other. It consists of a central part called the ***trunk,*** a posterior end or ***splenium,*** and an anterior end or ***genu*** (Figure 13.9)**.** A little below the corpus callosum, there is the third ventricle of the brain. A number of structures can be identified in relation to this ventricle. The ***interventricular foramen,*** through which the third ventricle communicates with the lateral ventricle, can be seen in the upper and anterior part. Posteroinferiorly, the ventricle is continuous with the ***cerebral aqueduct.*** The lateral wall of the ventricle is formed in greater part by a large mass of grey matter called the ***thalamus.*** The right and left thalami are usually interconnected (across the midline) by a strip of grey matter called the ***interthalamic connexus.*** The anteroinferior part of the lateral wall of the third ventricle is formed by a collection of grey matter that constitutes the ***hypothalamus.***

Above the thalamus, there is a bundle of fibres called the ***fornix.*** Posteriorly, the fornix is attached to the under surface of the corpus callosum, but anteriorly it disappears from view just in front of the interventricular foramen. Extending between the fornix and the corpus callosum, there is a thin lamina called the ***septum pellucidum (or septum lucidum)***, which separates the right and left lateral ventricles from each other. Removal of the septum pellucidum brings the interior of the lateral ventricle into view.

In the anterior wall of the third ventricle, there are the ***anterior commissure*** and the ***lamina terminalis.*** The

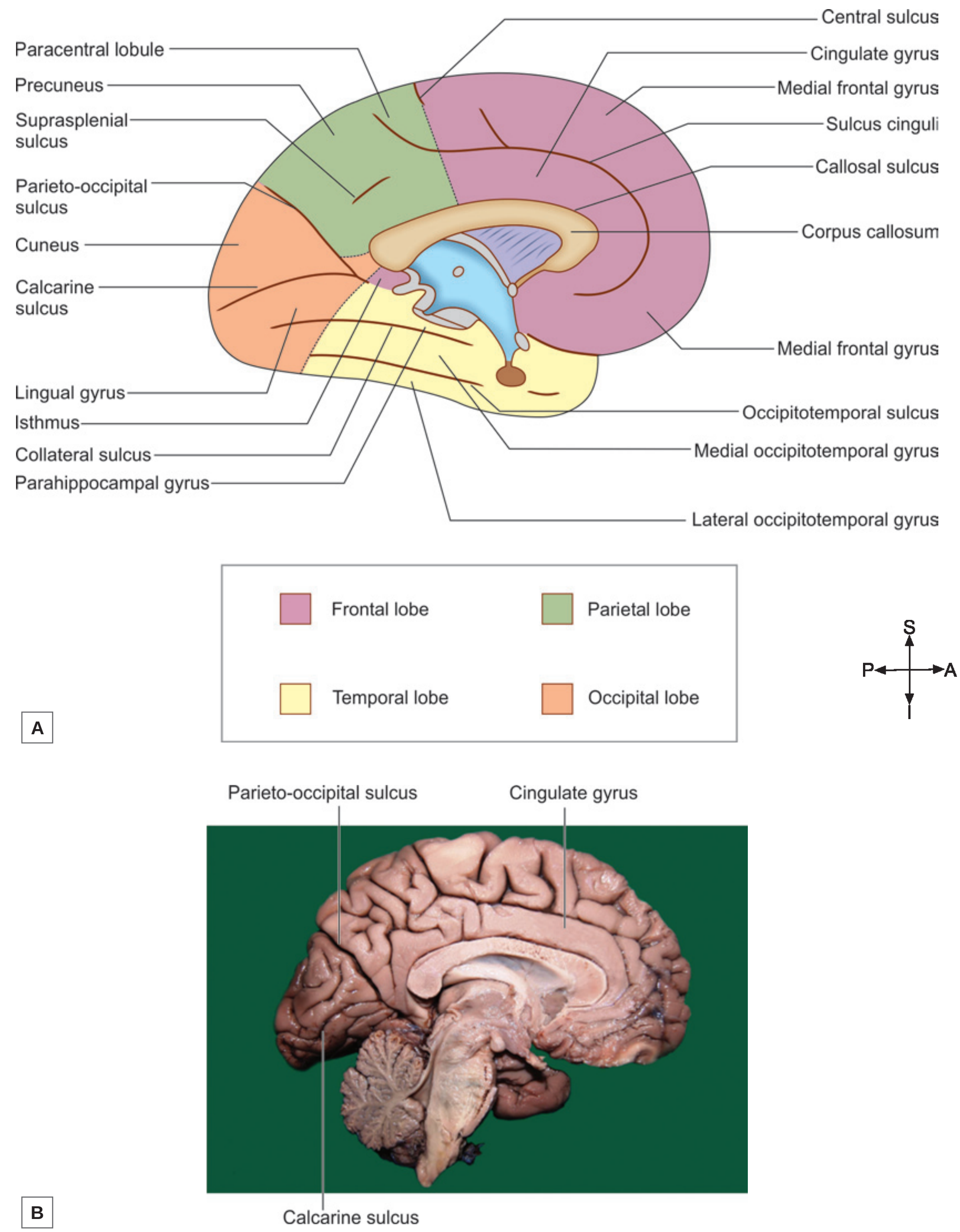

Figure 13.8: (**A**) The medial surface of the cerebral hemisphere showing gyri and sulci.The medial surface (pink) and the tentorial surface (green) are seen. The corpus callosum and some other structures connecting the two hemispheres have been cut across. (**B**) Medial surface of the cerebral hemisphere seen in a dissected brain specimen

anterior commissure is attached to the genu of the corpus callosum through a thin lamina of fibres that constitutes the ***rostrum*** of the corpus callosum. Below, the anterior commissure is continuous with the ***lamina terminalis,*** which is a thin lamina of nervous tissue. The lower end of the lamina terminalis is attached to the optic chiasma. Just in front of the lamina terminalis, there are the ***paraterminal gyrus*** and the ***parolfactory gyrus***. Posteriorly, the third

ventricle is related to the ***pineal body (or pineal gland)*** and inferiorly to the ***hypophysis cerebri.***

Above the corpus callosum (and also in front of and behind it), are the sulci and gyri of the medial surface of the hemisphere (Figure 13.8). The most prominent of the sulci is the ***cingulate sulcus,*** which follows a curved course parallel to the upper convex margin of the corpus callosum. Anteriorly, it ends below the rostrum of the corpus callosum. Posteriorly, it turns upwards to reach the superomedial border a little behind the upper end of the central sulcus. The area between the cingulate sulcus and the corpus callosum is called the ***gyrus cinguli.*** It is separated from the corpus callosum by the ***callosal sulcus.***

The part of the medial surface of the hemisphere between the cingulate sulcus and the superomedial border consists of two parts. The smaller posterior part, which is wound around the end of the central sulcus is called the ***paracentral lobule***. The large anterior part is called the ***medial frontal gyrus.*** These two parts are separated by a short sulcus continuous with the cingulate sulcus.

The part of the medial surface behind the paracentral lobule and the gyrus cinguli shows two major sulci that cut off a triangular area called the ***cuneus.*** The triangle is bounded anteriorly and above by the ***parieto-occipital sulcus,*** inferiorly by the ***calcarine sulcus,*** and posteriorly by the superomedial border of the hemisphere. The calcarine sulcus extends forwards beyond its junction with the parieto-occipital sulcus and ends a little below the splenium of the corpus callosum. The small area separating the splenium from the calcarine sulcus is called the ***isthmus.*** Between the parieto-occipital sulcus and the paracentral lobule, there is a quadrilateral area called the ***precuneus.*** Anteroinferiorly, the precuneus is separated from the posterior part of the gyrus cinguli by the ***suprasplenial (or subparietal) sulcus.***

The precuneus and the posterior part of the paracentral lobule form the medial surface of the parietal lobe.

Although the parieto-occipital and calcarine sulci appear to be continuous with each other on surface view, they are separated by the ***cuneate gyrus*** (or ***cuneolingual gyrus***), which lies in the depth of the area where the two sulci meet. The parts of the calcarine sulcus anterior and posterior to the junction with the parieto-occipital sulcus are separated by a deeply situated ***anterior cuneolingual gyrus***.

INFERIOR SURFACE OF CEREBRAL HEMISPHERE

When the cerebrum is separated from the hindbrain by cutting across the midbrain and is viewed from below, the structures seen are shown in Figure 13.10. Posterior to the midbrain, is the under surface of the splenium of the corpus callosum. Anterior to the midbrain, there is a depressed area called the ***interpeduncular fossa***.

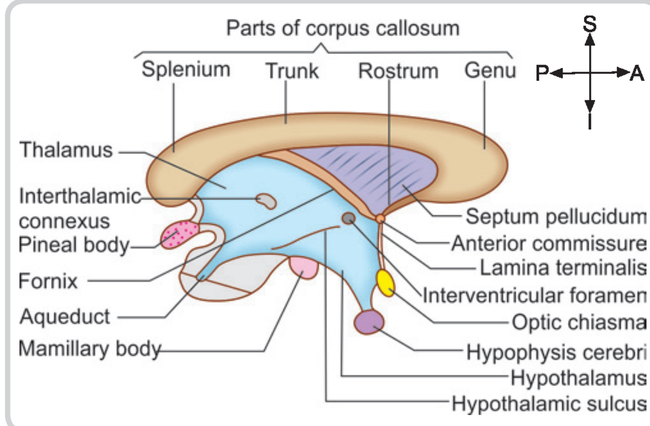

Figure 13.9: Enlarged view of the central part of the Figure 14.7 to show clearly some structures seen on the medial aspect of the cerebral hemisphere

The fossa is bounded in front by the ***optic chiasma*** and on the sides by the right and left ***optic tracts***. The optic tracts wind round the sides of the midbrain to terminate on its posterolateral aspect. In this region, two swellings, the ***medial and lateral geniculate bodies***, can be seen. Certain structures are seen within the interpeduncular fossa. These are closely related to the floor of the third ventricle (Figure 13.9). Anterior and medial to the crura of the midbrain, there are two rounded swellings called the ***mammillary bodies.*** Anterior to these bodies, there is a median elevation called the ***tuber cinereum,*** to which the infundibulum of the hypophysis cerebri is attached. The triangular interval between the mammillary bodies and the midbrain is pierced by numerous small blood vessels and is called the ***posterior perforated substance.*** A similar area lying on each side of the optic chiasma is called the ***anterior perforated substance***. The anterior perforated substance is bounded anterolaterally by the lateral olfactory stria and posterolaterally by the uncus. The anterior perforated substance is connected to the insula by a band of grey matter, called the ***limen insulae,*** which lies in the depth of the stem of the lateral sulcus.

In addition to these structures, there are the sulci and gyri on the orbital and tentorial parts of the inferior surface of the each cerebral hemisphere. These parts are separated from each other by the stem of the lateral sulcus.

Sulci and Gyri on Orbital Surface

Close to the medial border of the orbital surface, there is an anteroposterior sulcus called the ***olfactory sulcus*** because the olfactory bulb and tract lie superficial to it. The area medial to this sulcus is called the ***gyrus rectus***. The rest of the orbital surface is divided by an H-shaped ***orbital sulcus*** into ***anterior***, ***posterior***, ***medial,*** and ***lateral orbital gyri.***

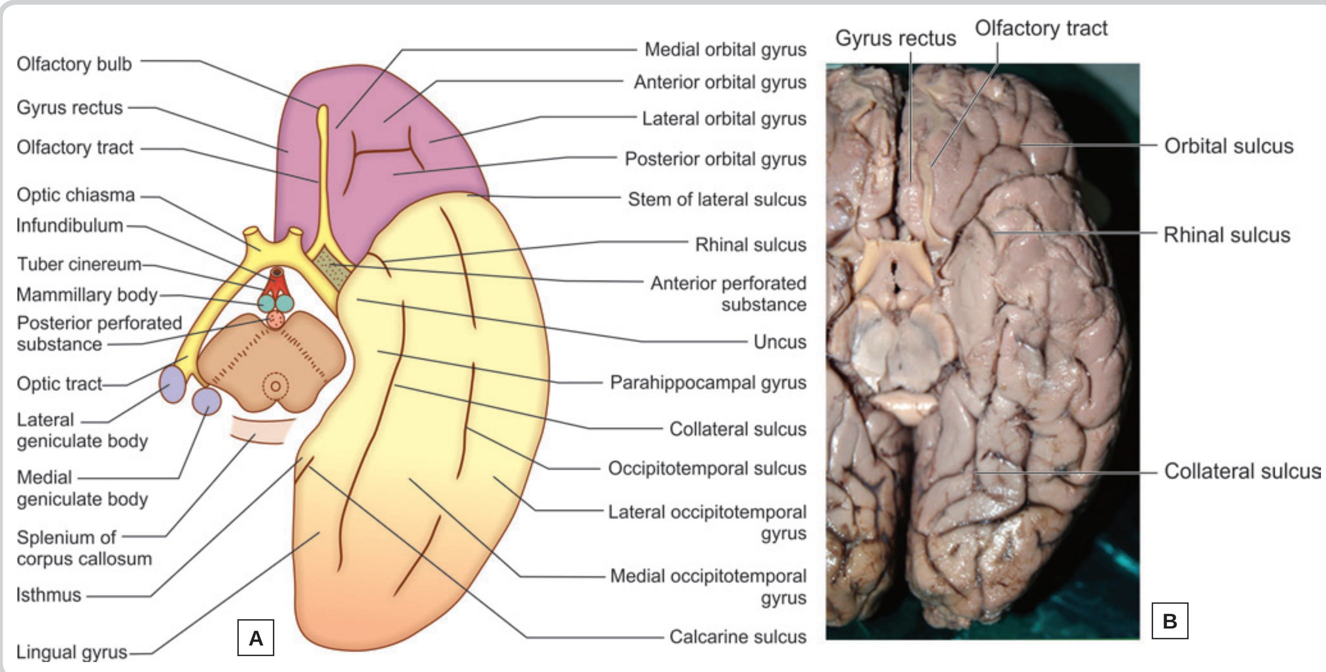

Figure 13.10: (**A**) Structures to be seen on the inferior aspect of the cerebrum. The midbrain has been cut across. (**B**) Inferior surface seen in a brain specimen

Sulci and Gyri on Tentorial Surface

The tentorial surface is marked by two major sulci that run in an anteroposterior direction. These are the ***collateral sulcus,*** medially and the ***occipitotemporal sulcus,*** laterally. The posterior part of the collateral sulcus runs parallel to the calcarine sulcus; the area between them is the ***lingual gyrus.*** Anteriorly, the lingual gyrus becomes continuous with the ***parahippocampal gyrus,*** which is related medially to the midbrain and to the interpeduncular fossa. The anterior end of the parahippocampal gyrus is cut off from the curved temporal pole of the hemisphere by a curved ***rhinal sulcus.*** This part of the parahippocampal gyrus forms a hook-like structure called the ***uncus,*** details of which are considered later. Posteriorly, the parahippocampal gyrus becomes continuous with the gyrus cinguli through the isthmus (Figure 13.8). The area between the collateral sulcus and the rhinal sulcus, medially and the occipitotemporal sulcus, laterally is the ***medial occipitotemporal gyrus.*** The area lateral to the occipitotemporal sulcus is called the ***lateral occipitotemporal gyrus.*** This gyrus is continuous (around the inferolateral margin of the cerebral hemisphere) with the inferior temporal gyrus.

STRUCTURE OF CEREBRAL CORTEX

Due to the presence of a large number of sulci, only about one-third of the total area of cerebral cortex is seen on the surface of the brain. The total area of the cerebral cortex is estimated to be about 2000 cm^2.

Like other masses of grey matter, the cerebral cortex contains the cell bodies of an innumerable number of neurons along with their processes, neuroglia, and blood vessels. The neurons are of various sizes and shapes. They establish extremely intricate connections with each other and with axons reaching the cortex from other masses of grey matter. Despite a very large volume of work on the subject, it is still not possible to explain many functions within the cerebral cortex.

NEURONS IN CEREBRAL CORTEX

Cortical neurons vary in size, shape of their cell bodies, and lengths, branching patterns, and orientation of their processes. The cerebral cortex consists of many types of nerve cells but two principal nerve cells are the pyramidal cells and stellate cells, which are described in detail below (Table 13.1 and Figure 13.11).

Table 13.1 | Nerve Cells of Cerebral Cortex

Pyramidal cells (P)	Cells of Martinotti (M)
Stellate cells (S)	Basket cells (B)
Fusiform cells (F)	Neurogliaform cells (N)
Horizontal cells of Cajal (H)	

Pyramidal Cells

They are the most abundant type of cortical neurons. In contrast, all other neurons in the cortex are referred to as nonpyramidal neurons. About two-thirds of all cortical neurons are pyramidal. Their cell bodies are triangular,

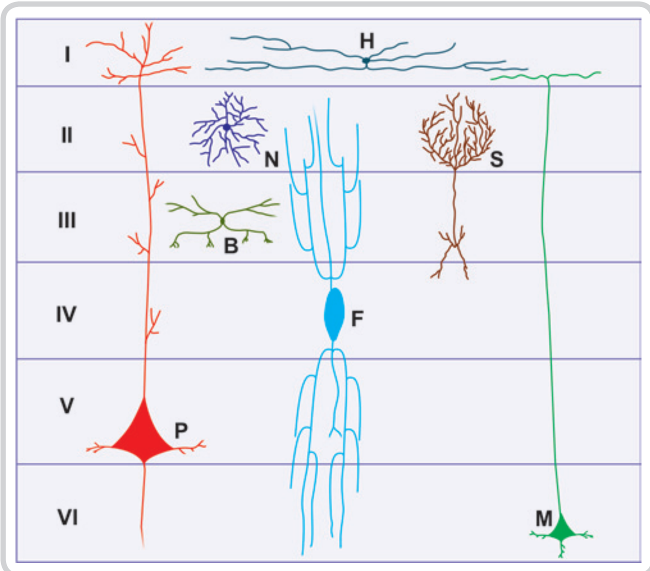

Figure 13.11: Some of the cell types to be seen in the cerebral cortex. Other varieties not shown include bipolar cells, Chandelier cells, and double bouquet cells.

with the apex generally directed towards the surface of the cortex. A large dendrite arises from the apex. Other dendrites arise from basal angles. The axon arises from the base of the pyramid. The processes of pyramidal cells extend vertically through the entire thickness of cortex and establish numerous synapses. The axon of a pyramidal cell may terminate in one of the following ways:

- It may travel to other regions like the basal ganglia, the brainstem, or the spinal cord. Fibres that leave the cortex commonly give off collaterals that terminate within the cortex.
- It may cross to the opposite side (through a commissure) and reach the corresponding region of the opposite hemisphere. Sometimes, it may reach a different region of the opposite hemisphere.
- It may enter the white matter to travel to another part of the cortex.
- It may be short and may terminate within the same area of the cortex.

The neurotransmitter used by pyramidal cells is either glutamate or aspartate.

Stellate Cells

The ***stellate neurons*** are relatively small and multipolar. They form about one-third of the total neuronal population of the cortex. Under low magnifications (and in preparations in which their processes are not demonstrated), these neurons look like granules. They have, therefore, been termed ***granular neurons*** by earlier workers. Stellate cells are of various types depending on their location and pattern of ramification of their processes. Their axons are short and end within the cortex. Their processes extend chiefly in a vertical direction within the cortex, but in some cases, they may be oriented horizontally. Some cells included under the term 'stellate' may be fusiform rather than stellate, with one large process arising at either end. Depending on the density of synaptic spines on their dendrites, stellate neurons are classified as ***spiny*** and ***nonspiny***.

In addition to the stellate and pyramidal nerurons, the cortex contains numerous other cell types like the fusiform cells, the horizontal cell, and the cell of Martinotti.

The neurotransmitter used by pyramidal cells is either glutamate or aspatate. In spiny stellate cells, it is glutamate, while in most nonspiny stellate cells, it is gamma-amino butyric acid (GABA).

The cortical neurons connect with the other neurons in the following manner:

- Projection neurons transmit impulses to the subcortical centers, viz. thalamus, brainstem, or spinal cord.
- Association neurons connect with other cortical nerve cells within the same cerebral hemisphere.
- Commissural neurons establish connection between the cortical nerve cells of the two cerebral hemispheres.

LAMINAE OF CEREBRAL CORTEX

On the basis of light microscopy (cell bodies displayed by Nissl method and the myelinated fibres stained by Weigert method), the cerebral cortex is described as having six

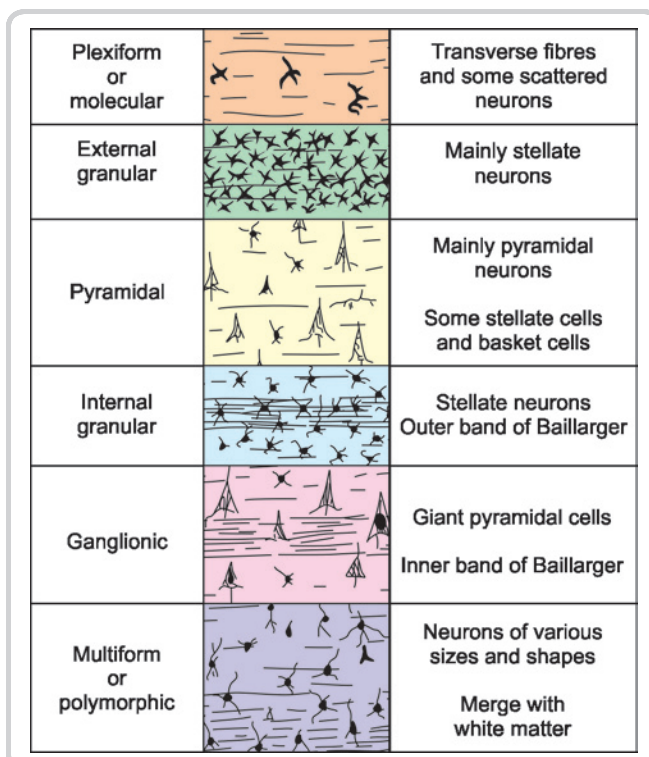

Figure 13.12: Laminae of cerebral cortex

layers or laminae (Figure 13.12). From the superficial to deep, these laminae are:

- Plexiform or molecular layer
- External granular layer
- Pyramidal cell layer
- Internal granular layer
- Ganglionic layer
- Multiform layer

The plexiform layer is predominantly made up of fibres, although a few cells are present. All the remaining layers contain both stellate and pyramidal neurons, as well as other types of neurons. The external and internal granular layers have predominance of stellate (granular) cells. The prominent neurons in the pyramidal layer and the ganglionic layer are pyramidal neurons. The largest pyramidal cells (giant pyramidal cells of Betz) are found in the ganglionic layer. The multiform layer contains cells of various sizes and shapes.

In addition to the cell bodies of neurons, the cortex contains abundant nerve fibres. Many of these are vertically oriented. Some of these fibres represent afferents entering the cortex. In addition to the vertical fibres, the cortex contains transversely running fibres that form prominent aggregations in certain situations. One such aggregation, present in the internal granular layer is called the ***external band of Baillarger***. Another, present in the ganglionic layer is called the ***internal band of Baillarger***. The space between the cell bodies of neurons is permeated by a dense plexus formed by their processes. This plexus is referred to as the ***neuropil***.

Relationship of Cortical Laminae to Incoming and Iutgoing Fibres

The main fibres entering or leaving a given area of cortex can be described as follows:

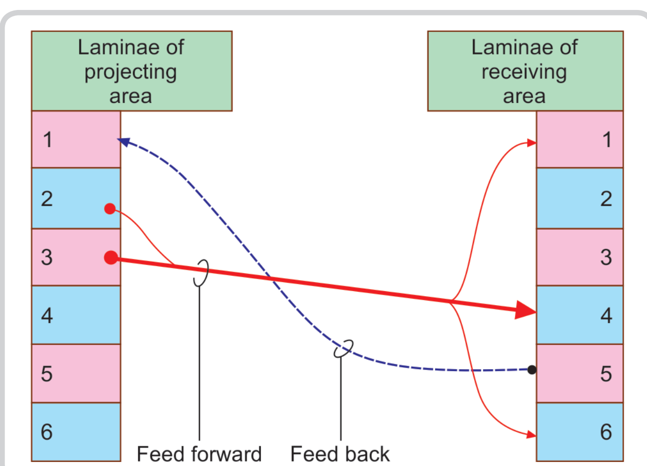

Figure 13.13: Concept of feed forward and feedback cortical connections

- Fibres projecting from one area of cortex to another are referred to as ***feed forward*** fibres. They arise mainly in lamina 3, with some from lamina 2. They terminate mainly in lamina 4 (but also in 1, 6 and others) of the receiving area of cortex (Figure 13.13).
- The receiving area sends a ***feedback*** to the area of cortex from it receives a feed forward projection. These feedback fibres arise in lamina 5 (of receiving cortex) and end in lamina 1 of the cortex from which the feed forward projection was received.
- The projections to the striatum (corticostriate fibres), to the spinal cord (corticospinal fibres), to pontine nuclei (corticopontine fibres), and to the medulla (corticobulbar fibres) all arise mainly from lamina 5 of the cortex.
- Corticothalamic projections arise from lamina 6.
- Major afferent fibres entering the cortex (e.g., from the thalamus; or feed forward fibres from other cortical areas) end mainly in lamina 4. Some reach laminae 1 and 6, while a few reach the remaining laminae.

VARIATIONS IN CORTICAL STRUCTURE

The structure of the cerebral cortex shows considerable variation from region to region, both in terms of thickness and the prominence of the various laminae described above. As already mentioned, finer variations form the basis of the subdivisions into Brodmann areas. Other workers divide the cortex into five broad varieties. These are as follows:

- In the ***agranular cortex,*** the external and internal granular laminae are inconspicuous. This type of cortex is seen most typically in the precentral gyrus (area 4) and is, therefore, typical of 'motor' areas. It is also seen in areas 6, 8, and 44 and in parts of the limbic system.
- In the ***granular cortex,*** the granular layers are highly developed, while the pyramidal and ganglionic layers are poorly developed or absent. This type of cortex is seen most typically in 'sensory' areas, including the postcentral gyrus, the visual cortex, and the acoustic areas (see below). In the visual area, the external band

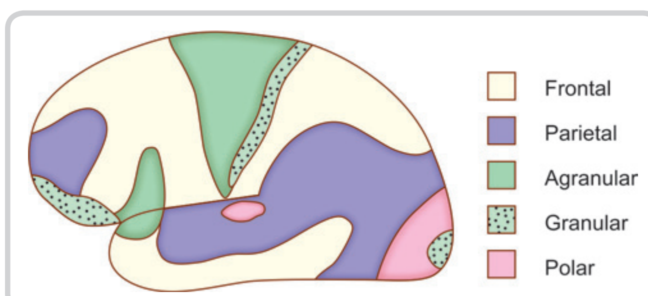

Figure 13.14: Superolateral surface of the cerebral hemisphere showing the distribution of cortical areas having different types of histological structure

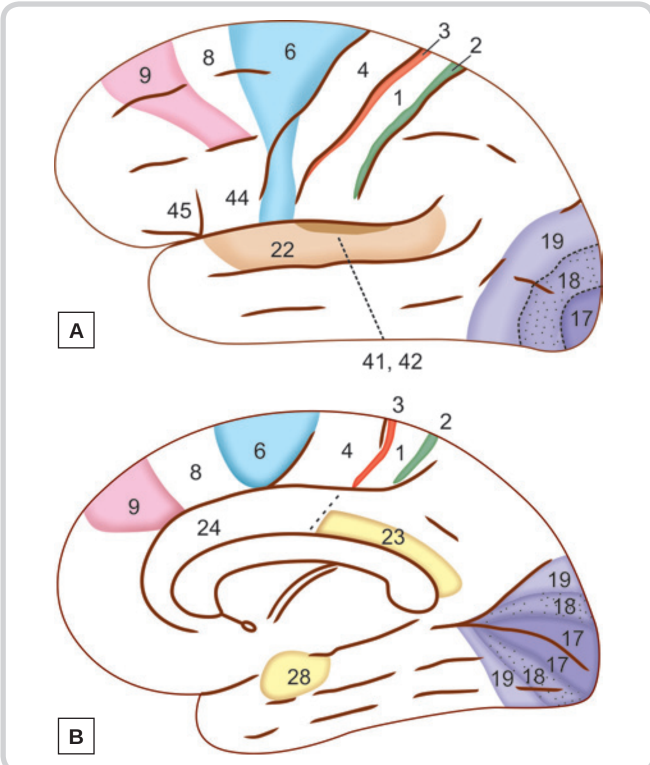

Figure 13.15: (**A**) Location of some of the areas of Brodmann on the superolateral aspect and (**B**) on the medial aspect of the cerebral hemisphere

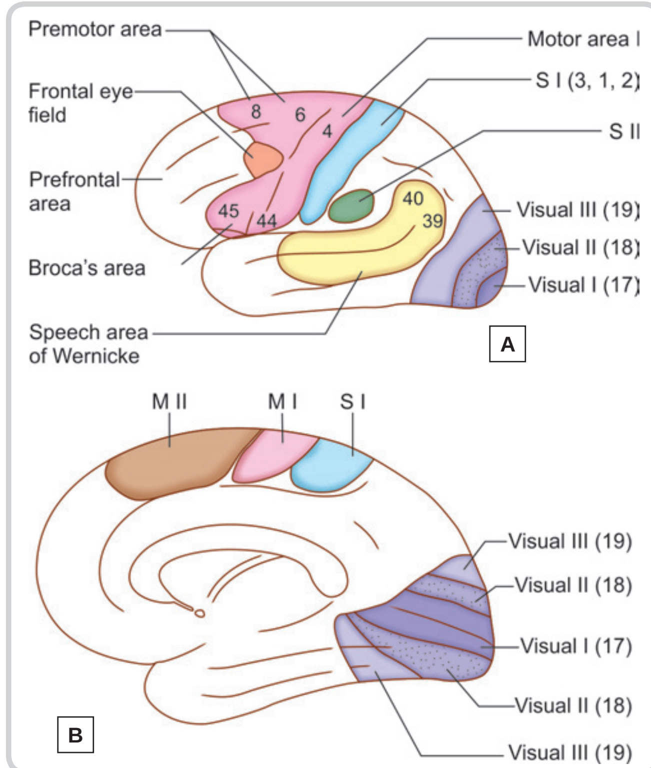

Figure 13.16: (**A**) Functional areas on the superolateral aspect of the cerebral hemisphere and (**B**) on the medial aspect (recent concept)

of Baillarger is prominent and forms a white line that can be seen with the naked eye when the region is freshly cut across. This ***stria of Gennari*** gives the name ***striate cortex*** to the visual cortex.

Between these two extremes represented by the agranular and granular varieties of cortex, three intermediate types are described as follows:

- ***Frontal cortex***
- ***Parietal cortex***
- ***Polar cortex***

The frontal type is nearest to the agranular cortex, the pyramidal cells being most prominent, while the polar type is nearest to the granular cortex. The terms frontal and parietal are unfortunate, as these types are not confined to the regions suggested by their names. The approximate distribution of the five types of cortex described above, on the superolateral surface of the cerebral hemisphere, is shown in Figure 13.14.

Phylogenetcally, cerebral cortex is of three types:

- Archipallium (Ancient cortex)—Only three laminae are seen e.g. Hippocampal gyrus.
- Paleopallium (Primal cortex)—Four to five laminae are seen e.g. Subiculum.
- Neopallium (New cortex)—Six laminae are seen e.g. Precentral gyrus and postcentral gyrus

FUNCTIONAL AREAS OF CEREBRAL CORTEX

Some areas of the cerebral cortex can be assigned specific functions. These areas can be defined in terms of known sulci and gyri. However, some areas are commonly referred to by numbers, and it is necessary to know what these numbers mean. Various workers who have studied the microscopic structure of the cerebral cortex, have found that there is a considerable variation from region to region. They have also found that these variations do not necessarily follow the boundaries of sulci and gyri, but often cut across them. Various authors have worked out 'maps' of the cerebral cortex indicating areas of differing structures. The best known scheme is that of Brodmann, who represented different areas by numbers. Although the functional significance of the areas is open to question, areas of the cortex are very frequently referred to by Brodmann numbers. It is, therefore, necessary to be familiar with them. The numbers most commonly referred to are indicated in Figure 13.15.

Primary Motor Area (Area 4 of Brodmann)

The motor area (MI) is located in the precentral gyrus on the superolateral surface of the hemisphere (Figure 13.16) and in the anterior part of the paracentral lobule on the medial surface. It corresponds to area 4 of Brodmann. When these

areas are stimulated electrically, movements occur in various parts of the body. Anatomically, these areas give origin to projection fibres that form the corticospinal and corticonuclear tracts.

Specific regions within the area are responsible for movements in specific parts of the body.

Stimulation of the paracentral lobule produces movement in the lower limbs. The trunk and upper limb are represented in the upper part of the precentral gyrus, while the face and head are represented in the lower part of the gyrus i.e. human body is represented in an upside down manner. Figure 13.17 shows the motor homunculus (latin for "little man") in the motor area with proportional somatotopical representation.

Another feature of interest is that the area of cortex representing a part of the body is not proportional to the size of the part, but rather to intricacy of movements in the region. Thus, relatively large areas of cortex represents the hands and lips.

Premotor Area (Areas 6 and 8 of Brodmann)

The premotor area is located just anterior to the motor area. It occupies the posterior parts of the superior, middle and inferior frontal gyri (Figure 13.16). The part of the premotor area located in the superior and middle frontal gyri corresponds to areas 6 and 8 of Brodmann (Figure 13.15).

Stimulation of the premotor area results in movements, but these are somewhat more intricate than those produced by stimulation of the motor area.

The distinction between motor and premotor areas is vague and the entire area is sometimes described as the primary motor area. Studies on areas of the cortex giving origin to corticospinal fibres show that they arise from a wide area covering the main and supplementary motor areas, premotor area, and many areas in the parietal lobe (SI including areas 3, 2, and 1, area 5, and SII in the parietal operculum). It is obvious that this area is not coextensive with the definition of motor areas. Some studies claim that only 20–30% of corticospinal fibres arise from area 4, and that as many as 50% may have their origin in the parietal lobe. In relation to motor function, the site of termination of corticospinal fibres in spinal grey matter becomes significant. Most fibres that descend from the parietal lobe end in the dorsal grey column; while those ending in the ventral grey column are predominantly from the frontal lobe. The latter appear to be the ones most important for motor control.

The premotor area appears to be responsible for programming the intended movements and control of movements in progress. It is divisible into a dorsal and a ventral area. The dorsal area is concerned with movements initiated by the individual, while the ventral area is concerned with control of movements that take place in response to external stimulation.

The cortex of the motor area is characterized by the presence of large pyramidal cells (giant pyramidal cells of Betz). These cells were considered to be the source of all corticospinal fibres, but as discussed above, they also come from parietal lobe.

It has been estimated that the size of the soma of a neuron is proportional to the total volume of its processes. It follows that neurons with very long axons will have large somata. Purkinje cells that give origin to corticospinal fibres descending to sacral segments of the spinal cord are, therefore, expected to be amongst the largest pyramidal cells.

Apart from its corticospinal output, the motor area is connected (in a point-to-point manner) with the main sensory cortex (SI). This explains why neurons in area 4 are responsive to peripheral stimulation. Area 4 receives afferents from the posterior part of the ventral lateral nucleus of the thalamus. This nucleus receives fibres from cerebellar nuclei. In this way, the cerebellum projects to area 4. Area 4 also receives fibres from some other parts of the thalamus, the hypothalamus, and some other parts of the cerebral cortex (including the primary sensory area SI).

Supplementary Motor Area (MII)

This lies on the medial surface of the cerebral hemisphere on the medial frontal gyrus. It has extensions of Broadmann's areas 4,6 and 8 on to the medial surface.

Frontal Eye Field

The frontal eye field lies in the middle frontal gyrus anterior to the precentral gyrus (Figure 13.16). It includes parts of areas 6, 8, and 9. Stimulation of this area causes both eyes to move to the opposite side. These are called ***conjugate movements.*** Movements of the head and dilatation of the pupil may also occur. This area is connected to the cortex of the occipital lobe that is concerned with vision. It is also connected to the thalamus (medial dorsal nucleus).

Note: The frontal eye field and the motor speech area (of Broca) are parts of the premotor area.

Prefrontal Areas

The part of the frontal lobe excluding the motor and premotor areas is referred to as the prefrontal area (Figure 13.16). It includes the parts of the frontal gyri anterior to the premotor area, the orbital gyri, most of the medial frontal gyrus, and the anterior part of the gyrus cinguli.

The prefrontal area has numerous connections with the thalamus, the corpus striatum, the limbic system, the hypothalamus, the reticular formation, the cranial nerve nuclei, and the pontine nuclei. These connections suggest that this area is concerned with both somatic and visceral activity. Injury to some parts of this region makes the person not only more docile but also negligent and lacking

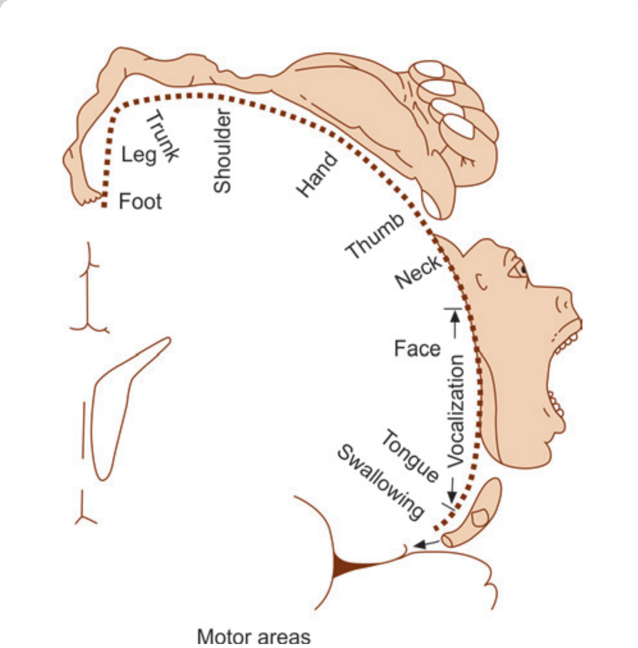

Figure 13.17: The motor homunculus

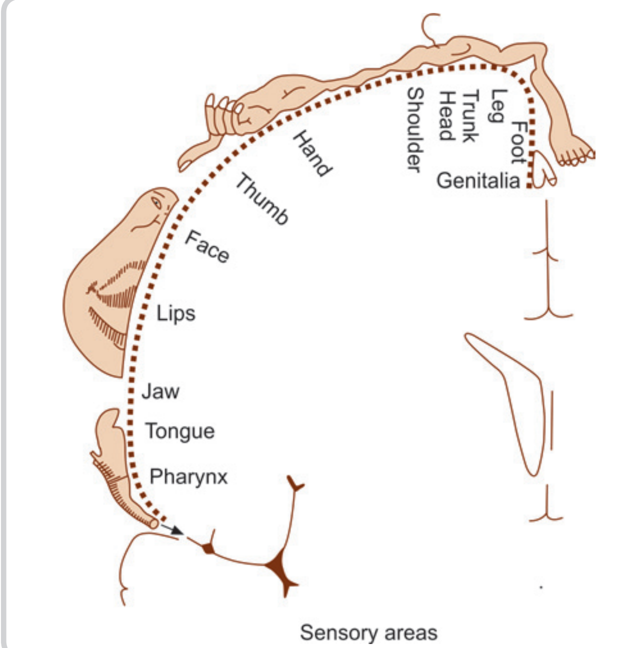

Figure 13.18: The sensory homunculus

in concentration. The prefrontal area is concerned with normal expression of emotions and the ability to predict consequences of actions. The medial part of the prefrontal area is associated with auditory and visual functions.

Motor Speech Area

The motor speech area of Broca lies in the inferior frontal gyrus (Broadmann areas 44 and 45, Figures 13.15 and 13.16). Injury to this region results in inability to speak (***aphasia*)**, even though the muscles concerned are not paralyzed. These effects occur only if damage occurs in the left hemisphere in right-handed persons and in the right hemisphere in left-handed persons. In other words, motor control of speech is confined to one hemisphere, which controls the dominant upper limb.

Apart from the motor speech area of Broca, there are two other areas concerned with control of speech. One of these is located in the temporal and parietal lobes (***sensory speech area of Wernicke***), while the other is located in the ***supplementary motor area (MII)***.

Clinical Correlation

Effects of damage to motor areas

- A localized lesion of the primary motor area normally produces contralateral monoplegia. An extensive lesion can cause hemiplegia.
- Lesions of the premotor area have an adverse effect on skilled movements.
- Lesions of the frontal eye field result in deviation of both eyes to the side of lesion.
- Lesions of the motor speech area destroy the ability to speak.
- Lesions of the prefrontal areas lead to personality changes.

Sensory Area

The sensory area is located in the postcentral gyrus and is called the ***first somatosensory area (SI)*** (Figure 13.16**).** It corresponds to areas 3, 1, 2 of Brodmann. It also extends onto the medial surface of the hemisphere where it lies in the posterior part of the paracentral lobule. Responses can be recorded from the sensory area when individual parts of the body are stimulated.

It receives projections from the ventral posteromedial and ventral posterolateral nuclei of the thalamus, conveying impulses received through the medial, spinal, and trigeminal lemnisci.

A definite representation of various parts of the body can be mapped out in the sensory area. It corresponds to that in the motor area, in that the body is represented upside down. The area of cortex that receives sensations from a particular part of the body is not proportional to the size of that part but rather to the complexity of sensations received from it. Thus, the digits, the lips, and the tongue have a disproportionately large representation (Figure 13.18).

It has also been shown that different sensations may be represented in different parts within the area. Unit

recordings show that area 2 is concerned mainly with proprioceptive impulses, while area 3 responds only to cutaneous stimuli.

A second area predominantly somatosensory in function (***second somatosensory area or SII***) has been described in relation to the superior lip of the posterior ramus of the lateral sulcus (Figure 13.16).

The sensory speech area of Wernicke lies in the posterior part of the superior and middle temporal gyri. It extends into areas 39 and 40 of the parietal lobe. This area is responsible for interpretation of speech.

Parts of the superior parietal lobule (areas 5 and 7) help us recognize shape, size, and texture of objects.

Like area SI, SII receives fibres from the ventral posterior nucleus of the thalamus. It also receives fibres from SI. Descending fibres from SII reach the spinal cord, the nuclei gracilis and cuneatus, and the main trigeminal nucleus. Neurons in SII respond best to intermittent stimulation, for example, vibration. SII may be responsible for perception of pain and temperature.

A small part of the primary sensory area, probably within area 2, serves as ***cortical vestibular area***.

Clinical Correlation

Effects of damage to sensory areas are as follows:

- Damage to the first somatosensory area causes loss of sensation (both exteroceptive and priopriocepive) from the opposite side of the body.
- Damage to the second sensory area may lead to inability to appreciate pain and temperature.
- Damage to some areas behind the main sensory area (areas 5 and 7) interferes with ability to identify objects by feeling them.
- Damage to the area of Wernicke leads to failure to understand speech.

Visual Areas

The areas concerned with vision are located in the occipital lobe, mainly on the medial surface, both above and below the calcarine sulcus (area 17). Area 17 extends into the cuneus and into the lingual gyrus (Figure 13.15). Posteriorly, it may extend onto the superolateral surface, where it is limited (anteriorly) by the lunate sulcus.

It receives fibres of the optic radiation. It is also called the ***striate cortex***.

In addition to the striate cortex, additional areas of cortex responding to visual inputs are described. Area 18 (***parastriate area***) is the second visual area, and area 19 (***peristriate area***) is the third visual area.

Areas 18 and 19 are responsible mainly for interpretation of visual impulses reaching area 17, and they are often described as ***psychovisual areas***.

A modified nomenclature recognizing five visual areas has been described as follows:

- First visual area (V1) in area 17
- Second visual area (V2) occupying the greater part of area 18, but not the whole of it
- Third visual area (V3) occupying a narrow strip over the anterior part of area 18
- Fourth visual area (V4) within area 19
- Fifth visual area (V5) at the posterior end of the superior temporal gyrus.

The visual areas give off efferent fibres also. These reach various parts of the cerebral cortex in both hemispheres. In particular, they reach the frontal eye field, which is concerned with eye movements. Like other 'sensory' areas, the visual areas also connect with functionally related motor areas. This is substantiated by the fact that movements of the eyeballs and head can be produced by stimulation of

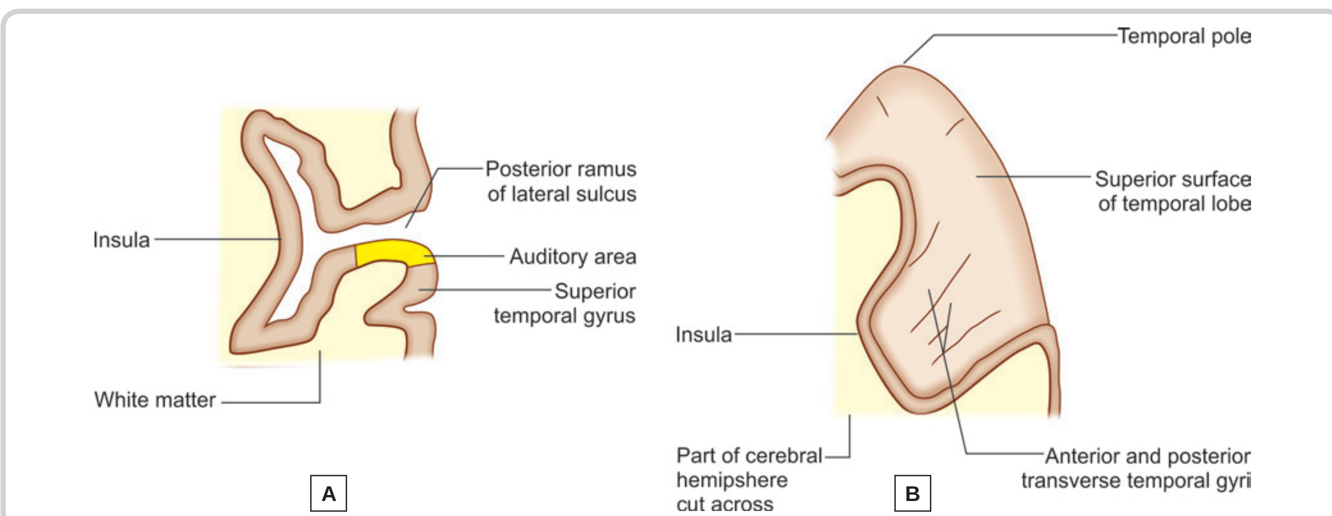

Figure 13.19: (**A**) Location of the acoustic area in relation to the superior temporal gyrus. (**B**) Upper surface of the superior temporal gyrus to show transverse temporal gyri

areas 17 and 18, which constitute the ***occipital eye field.*** Efferents from the visual areas also reach the superior colliculus, the pretectal region, and the nuclei of cranial nerves supplying muscles that move the eyeballs. There is physiological evidence of a corticogeniculate projection. Fibres also reach the thalamus (pulvinar).

The total number of neurons seen in delimited vertical areas of cortex is remarkably constant in different regions. The cortex of the visual area has a much greater density of neurons than other parts of the cortex.

Auditory (Acoustic) Area

The acoustic area or the area for hearing is situated in the temporal lobe. It lies in that part of the superior temporal gyrus, which forms the inferior wall of the posterior ramus of the lateral sulcus (Figure 13.19A). In this location, there are two short oblique gyri called the anterior and posterior ***transverse temporal gyri*** (areas 41 and 42; Figure 13.19B). The auditory area lies in the anterior transverse temporal gyrus (area 41) and extends to a small extent onto the surface of the hemisphere in the superior temporal gyrus (areas 41 and 42 in Figure 13.15).

As in the case of the visual areas, it has been shown that fibres of the acoustic radiation end not only in the primary auditory area but extend into neighboring areas also. These include a secondary acoustic area lying in the superior temporal gyrus anterior to A1. A number of other auditory areas have been described.

Efferent fibres arising in the acoustic areas project to the medial geniculate body and to the inferior colliculus and possibly also reach motor nuclei of cranial nerves. Some of these efferents may influence the state of contraction of the stapedius and tensor tympani muscles. The acoustic areas are also connected with other parts of the cerebral cortex.

Essentially, the fibres of each lateral lemniscus are bilateral. Hence, the acoustic areas in each cerebral cortex receive fibres from both the right and left cochleae. The close relationship of the acoustic areas to Wernicke's speech area is to be noted. The association is significant in view of the obvious relationship between hearing and speech.

Clinical Correlation

As the auditory areas receive impulses from both sides, a lesion on one side produces only partial loss of hearing. Lesions in the secondary auditory area (area 22) interferes with interpretation of speech (***word deafness***).

Pattern of corticocortical connections

It has been recognized that cortical areas have numerous connections with other parts of the cerebral cortex. Investigations show that there is a pattern in these connections and that the pattern has important physiological implications (Figure 13.20).

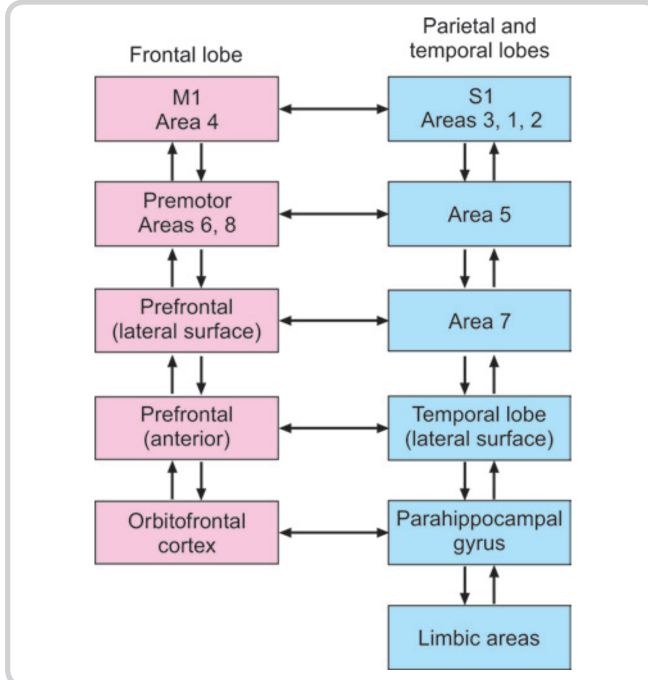

Figure 13.20: Scheme to show the pattern of interconnections between areas of cerebral cortex

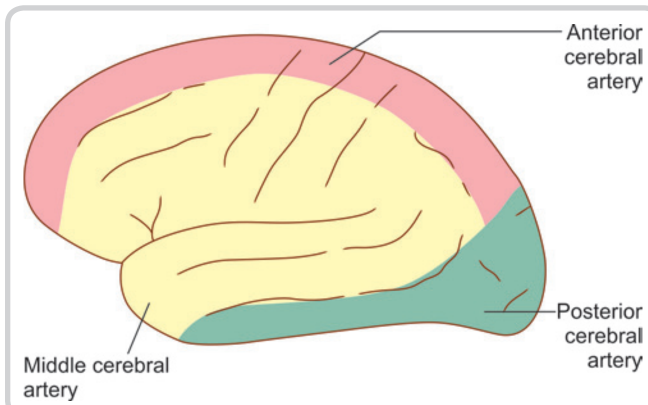

Fig. 13.21: Distribution of the anterior, posterior and middle cerebral arteries on the superolateral surface of the cerebral hemisphere.

- The first feature of this concept is that major sensory areas of cortex send feedforward projections to adjoining areas of cortex and the latter, in turn, project to other contiguous areas. Through a series of such connections, the sensory areas get connected to the limbic cortex.
- The second feature is that main sensory areas (in the parietal, occipital, and temporal lobes) are reciprocally connected to areas in the frontal lobe.

These features can be clarified by considering the connections of the primary sensory area (SI) as follows:

- The primary sensory area (SI) sends a feedforward projection to area 5 (lying in the superior parietal lobule). Area 5 projects to area 7 (lying further back in

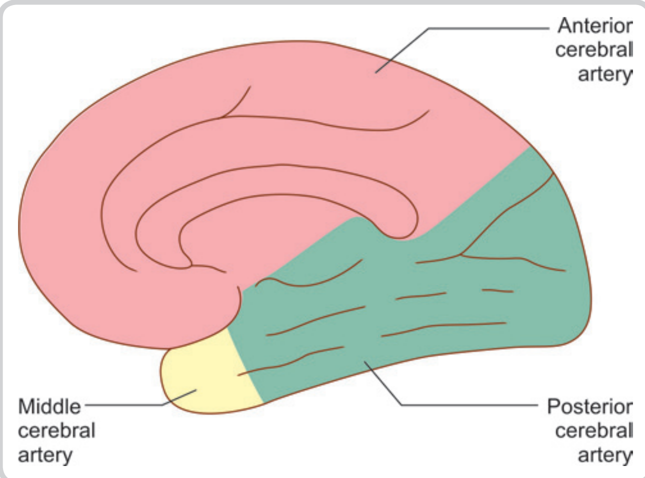

Fig. 13.22: Arteries supplying the medial surface of the cerebral hemisphere

the parietal lobe). Area 7 projects to the temporal lobe in the region of the superior temporal sulcus. This region projects to the parahippocampal gyrus, which in turn projects to the limbic cortex. The main connection is in the 'forward' direction, but all connections are reciprocal (Figure 13.19).

- Each of the main sensory areas is connected to an area in the frontal lobe. SI is connected to MI. Note that these areas are contiguous to one another. Area 5 is connected to the premotor area. In a similar manner, the parietal and temporal lobes are connected to areas in the frontal lobe, progressively farther removed from the motor area. This indicates a close functional linking of sensory and motor regions at various levels. All connections are reciprocal.
- As with the somatosensory area, the visual and auditory areas are also connected to the limbic cortex through a series of 'relays'. These are also connected reciprocally to the frontal lobe.

It is, therefore, not surprising that neurons responding to somatic, visual, and auditory impulses are widely scattered in the cerebral cortex, and that these are closely linked with motor responses.

ARTERIAL SUPPLY OF CEREBRAL CORTEX

The cerebral cortex is supplied by cortical branches of the anterior, middle, and posterior cerebral arteries.

Superolateral Surface

The greater part of the superolateral surface is supplied by the middle cerebral artery (Figure 13.21). The areas not supplied by this artery are as follows:

- A strip half to one inch wide along the superomedial border, extending from the frontal pole to the parieto-occipital sulcus is supplied by the anterior cerebral artery.

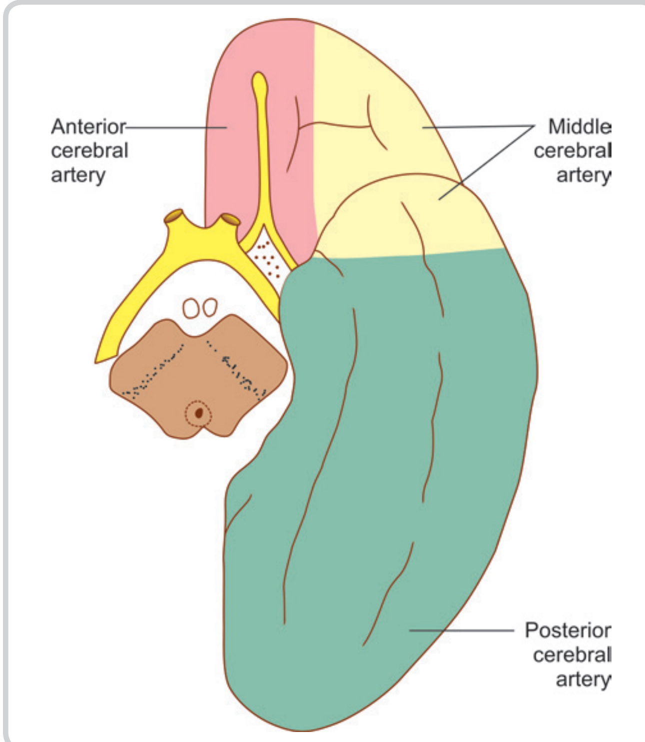

Fig. 13.23: Arteries supplying the orbital and tentorial surfaces of the cerebral hemisphere

- The area belonging to the occipital lobe is supplied by the posterior cerebral artery.
- The inferior temporal gyrus (excluding the part adjoining the temporal pole) is also supplied by the posterior cerebral artery.

Medial Surface

The main artery supplying the medial surface is the anterior cerebral artery (Figure 13.22). The area of this surface belonging to the occipital lobe is supplied by the posterior cerebral artery.

Inferior Surface

The lateral part of the orbital surface is supplied by the middle cerebral artery and the medial part by the anterior cerebral artery (Figure 13.23).

The tentorial surface is supplied by the posterior cerebral artery. The temporal pole is, however, supplied by the middle cerebral artery (Figure 13.23).

Clinical Correlation

Effects of occlusion of unilateral anterior cerebral artery:

- Contralateral monoplegia of lower limb – involvement of the upper part of the motor area

- Contralateral anaesthesia of lower limb – involvement of the upper part of the sensory area
- Astereognosis –involvement of superior parietal lobule

Bilateral involvement in case of unpaired anterior cerebral artery

- Personality changes, i.e. attention deficit, difficulty in planning, emotional lability (excessive emotional reactions and frequent mood changes), inappropriate social behaviour, apathy, abulia (loss of will power) – involvement of prefrontal cortex
- Uninhibited bladder – involvement of medial frontal cortex
- Cortical paraplegia – involvement of paracentral lobule

Effects of occlusion of middle cerebral artery:

- Contralateral hemiplegia and loss of sensations (The face and arms are most affected while lower limb shows slight weakness due to cerebral oedema that is associated with a large infarct) – involvement of primary motor and somatosensory cortex
- Astereognosis or tactile agnosia – involement of somesthetic association area
- Hearing may be slightly affected in both ears – involvement of primary auditory area
- Aphasia, if the thrombosis is in the left hemisphere – involvement of Broca's, Wernicke's areas and/or involvement of arcuate fasciculus connecting the two areas
- Aprosodia (prosody means rhythm, pitch, stress, intonation of speech), if the thrombosis is in the right hemisphere – involvement of similar areas of right hemisphere
- Word deafness / auditory verbal agnosia – involvement of auditory association area of left side
- Acalculia, anomia, finger agnosia, left-right confusion – involvement of left inferior parietal lobule
- Left hemineglect, construction apraxia, dressing apraxia, anosognosia (unaware of the existence of the disability) – involvement of right inferior parietal lobule

Effects of occlusion of posterior cerebral artery:

- Contralateral homonymous hemianopia with macular sparing – involvement of primary visual cortex
- Visual hallucinations, distortion of colour vision – involvement of visual association area
- Pure word blindness / alexia – involvement of visual association area of left hemisphere
- Peripheral visual loss with macular sparing / Gun-barrel vision – bilateral involvement of primary visual cortex

Transcortical infarcts:

Infarcts of cerebral cortex in areas involving junctional territories (watershed infarcts) of anterior and middle cerebral arteries or middle and posterior territories or both. Transcortical infarcts of the left hemisphere produces various types of aphasias:

- Transcortical motor aphasia involving watershed infarcts of anterior and middle cerebral arteries affects middle frontal lobe bordering on Broca's area. This results in expressive (non-fluent) aphasia similar to Broca's aphasia. However, because the arcuate fasciculus is spared, repetition is not affected.
- Transcortical sensory aphasia involving watershed infarcts of middle and posterior cerebral arteries affects middle temporal lobe bordering on Wernicke's area. This results in receptive (fluent) aphasia with paraphasia, neologism and jargons, similar to Wernicke's aphasia. However, again, because the arcuate fasciculus is spared, repetition is not affected.
- Transcortical mixed aphasia involving watershed infarcts of middle cerebral artery with both anterior and posterior cerebral arteries results in a clinical condition similar to global aphasia. However, here too, repetition is unaffected.

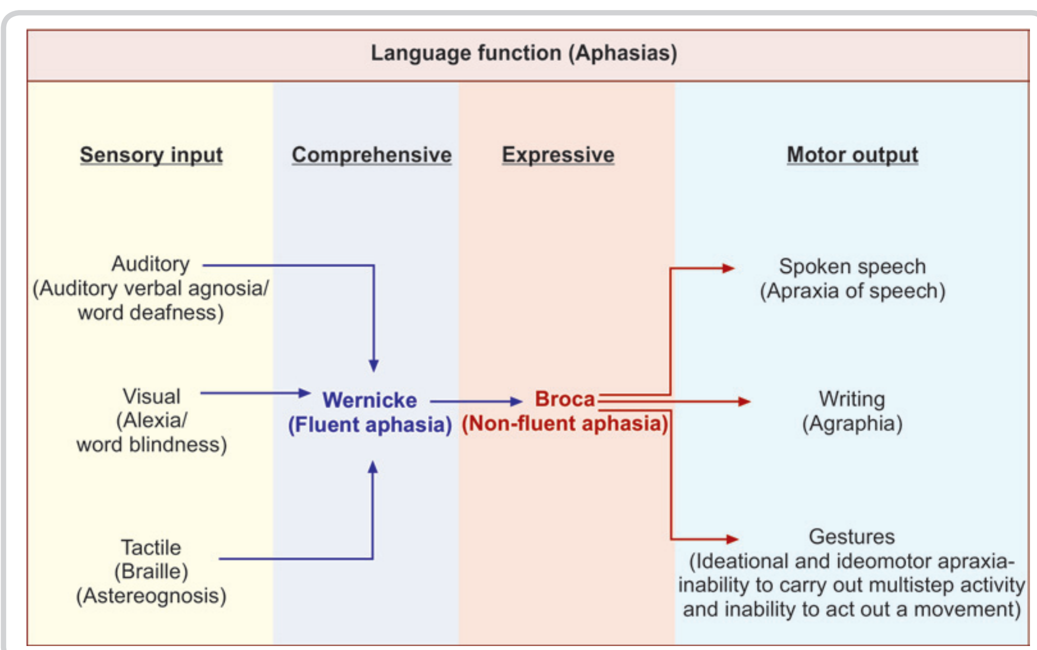

Fig. 13.24: A comprehensive look at using words as symbol of communication (Language function)

Table 13.2 │ Classification of Aphasia				
S No.	**Type of aphasia**	**Comprehension**	**Repetition**	**Expression**
1	Broca's aphasia	Good	Poor	Poor
2	Wernicke's aphasia	Poor	Poor	Good
3	Conduction aphasia	Good	Poor	Good
4	Global aphasia	Poor	Poor	Poor
5	Transcortical motor aphasia	Good	Good	Poor
6	Transcortical sensory aphasia	Poor	Good	Good
7	Transcortical mixed aphasia	Poor	Good	Poor

How does the (left) cerebral hemisphere use and interpret "words" as symbols of communication (language) and how do cortical disorders result in various types of "speech" disturbances (aphasias) is seen in Figure 13.24 and Table 13.2. Such lesions of the cerebral cortex could be caused by vascular accidents, tumours and injuries. A summary of lesion of various areas in the cerebral cortex are tabulated below (Table 13.3).

Table 13.3 │ Lesions of Various Areas in the Cerebral Cortex (Brodmann no. in Brackets) and Their Effects	
Site of lesion	**Result of Lesion**
Primary motor area (4)	***Epileptic seizures***–Due to irritative lesion ***Hemiplegia*** (contralateral flaccid paralysis)
Premotor area (6)	***Apraxia*** (difficulty in performing skilled movements)
Frontal eye field (8)	Contralateral voluntary ***conjugate movements of the eye is lost*** and the eye deviates to the side of lesion. However, pursuit movements on both sides are normal (controlled by occipital lobe)
Broca's motor speech area (44, 45)	***Expressive/motor aphasia***–Difficulty in spoken speech or writing (***agraphia***). Non-fluent speech and telegraphic language. Key words spoken are normal
Supplementary motor area M II	No permanent loss of movement, bilateral ***flexor hypotonia*** is present
Sensory speech area of Wernicke (posterior 22, inferior 39, 40)	***Receptive aphasia***–Loss of ability to understand spoken and written speech. Spoken speech is fluent but contains paraphasias (substitution of a word with a non-word, out of context word, and neologism)
Prefrontal area (9, 10, 11, 12)	***Personality changes***–Attention deficit, difficulty in planning, emotional lability, inappropriate social behaviour, apathy, abulia
Primary somesthetic area (3, 1, 2)	***Contralateral sensory loss***
Secondary somesthetic area (S II)	No recognizable sensory deficit
Somesthetic association area (5, 7)	***Astereognosis or tactile agnosia***–Inability to perceive the shape, size, roughness and texture of the objects by touch alone
Left inferior parietal lobule (39, 40)	Acalculia, anomia, finger agnosia, left-right confusion
Right inferior parietal lobule (39, 40)	Left hemineglect, construction apraxia, dressing apraxia, anosognosia (unaware of the existence of the disability)
Left perisylvian area	***Global aphasia***–Involvement of Broca's and Wernicke's area
Right perisylvian area	***Aprosodia***–Inability of a person to properly convey or interpret emotional prosody (prosody in language refers to the ranges of rhythm, pitch, stress, intonation, etc.)
Primary auditory area (41, 42)	Slight bilateral loss of hearing if one side is affected. Bilateral involvement of auditory area will result in ***deafness***.
Auditory association area (22)	***Word deafness (auditory verbal agnosia)***–Inability to interpret meaning of the sounds heard
Primary visual area (17)	***Contralateral homonymous hemianopia with macular sparing*** in vascular lesions (No macular sparing in trauma or tumours)
Visual association area (18, 19)	***Visual agnosia***–Loss of ability to recognize objects, ***Word blindness–alexia***

LATERALISATION OF CEREBRAL HEMISPHERES

The two hemispheres show bilateral asymmetry, both in structure and in function. Structurally, the posterior ramus of lateral sulcus generally is longer in the left hemisphere (planum temporale) than in the right hemisphere. Functionally, Broca's area and Wernicke's area are located in the left cerebral hemisphere in most left handed as well as right handed individuals.

Functional specialisation has been studied in split-brain patients (who had corpus callosotomy due to severe epilepsy). New methods that allow in-vivo comparison of the two hemispheres in normal individuals include positron emission tomography (PET) and functional magnetic resonance imaging (fMRI). These led to a better understanding of functional laterality of the cerebral hemispheres.

Language functions such as grammar, vocabulary and literal meaning are typically lateralised to the left hemisphere. The rhythm, stress, intonation of speech, the emotional state of the speaker, the presence of irony or sarcasm, emphasis, contrast and focus (all together called as prosody), are comprehended and expressed by the right hemisphere. Arithmetic ability (numerical calculation) and fact retrieval are associated with left hemisphere while geometric understanding, facial perception and artistic ability (including music) are predominantly right sided. Analytical, sequential and logical thinking are by left hemisphere while synthetic, spatial and creativity (lateral thinking/thinking out-of-the-box) are predominantly by the right.

The functional advantage of lateralisation allows each hemisphere to hone its specialisation rather than be a jack-of-all-and-master-of-none. The evolutionary advantage of lateralisation comes from the ability to perform separate parallel tasks, simultaneously, in each hemisphere of the brain. (Put all the eggs in one basket and watch that basket!)

Multiple Choice Questions

1. The cingulate gyrus is closely related to
   A. Corpus callosum
   B. Uncus
   C. Hippocampus
   D. Pineal body

2. The collateral sulcus is seen on which surface of the cerebral hemisphere?
   A. Superolateral
   B. Medical
   C. Orbital
   D. Tentorial

3. The paracentral lobule is located on which surface of cerebral hemisphere?
   A. Medial
   B. Tentorial
   C. Superolateral
   D. Orbital

4. Which structure lies posterior to the parieto-occipital sulcus on the medial surface of cerebral hemisphere
   A. Cuneus
   B. Precuneus
   C. Inferior parietal lobule
   D. Paracentral lobule

5. The artery related to the trunk of the corpus callosum is
   A. Middle cerebral
   B. Anterior cerebral
   C. Posterior cerebral
   D. Anterior choroidal

6. Which of the following parts of the body has maximum representation in the cerebral cortex?
   A. Thigh
   B. Trunk
   C. Hand
   D. Neck

7. Which of the following sulci is related to the primary visual area (17)?
   A. Calcarine
   B. Parieto-occipital
   C. Occipito-temporal
   D. Lateral occipital sulcus

8. On the superolateral surface of the cerebrum, which sulcus limits the primary visual area?
   A. Calcarine
   B. Parieto-occipital
   C. Lunate
   D. Lateral occipital

9. Lesion of Brodmann’s area 22 is associated with
   A. Auditory amnesia
   B. Agnosia
   C. Visual amnesia
   D. Alexia

10 Broca's area is located in
   A. Superior temporal gyrus
   B. Inferior parietal lobule
   C. Inferior frontal gyrus
   D. Angular gyrus

Answers

1. A **2.** D **3.** A **4.** A **5.** B **6.** C **7.** A **8.** C **9.** A **10.** C

Chapter 14

White Matter of Cerebral Hemispheres

Specific Learning Objectives

At the end of learning, the student shall be able to:

- Classify the white fibres of cerebrum into association, commissural and projection fibres
- Describe the corpus callosum
- Describe the internal capsule
- Explain the anatomical basis of stroke

INTRODUCTION

The interior of each cerebral hemisphere consists of a core of white matter, which is composed of myelinated nerve fibres. The fibres of white matter are classified into three types (Figures 14.1 and 14.2):

- Association fibres
- Commissural fibres
- Projection fibres

ASSOCIATION FIBRES

The association fibres connect different parts of the cerebral cortex of the same hemisphere to each other. These are of two types:

- ***Short association fibres,*** which connect the adjacent gyri to each other.
- ***Long association fibres,*** which connect the gyri located at a distance from each other.

Examples of Long Association Fibres

- The ***cingulum*** (girdle-shaped) is located within the cingulate gyrus. It extends from the paraterminal gyrus to the uncus. The cingulum is part of the Papez circuit of the limbic system.
- The ***uncinate fasciculus*** is a curved fibre bundle. It connects the inferior frontal gyrus and the orbital gyri of the frontal lobe to the hippocampus and amygdaloid nucleus of the temporal lobe. Thus, it connects the limbic areas of the cerebral hemispheres.
- The ***superior longitudinal fasciculus*** is a long bundle that begins in the frontal lobe and arches back via the parietal lobe to the occipital lobe, from where it turns into the temporal lobe. Thus, it connects the occipital lobe to the frontal eye field. (The arcuate fasciculus

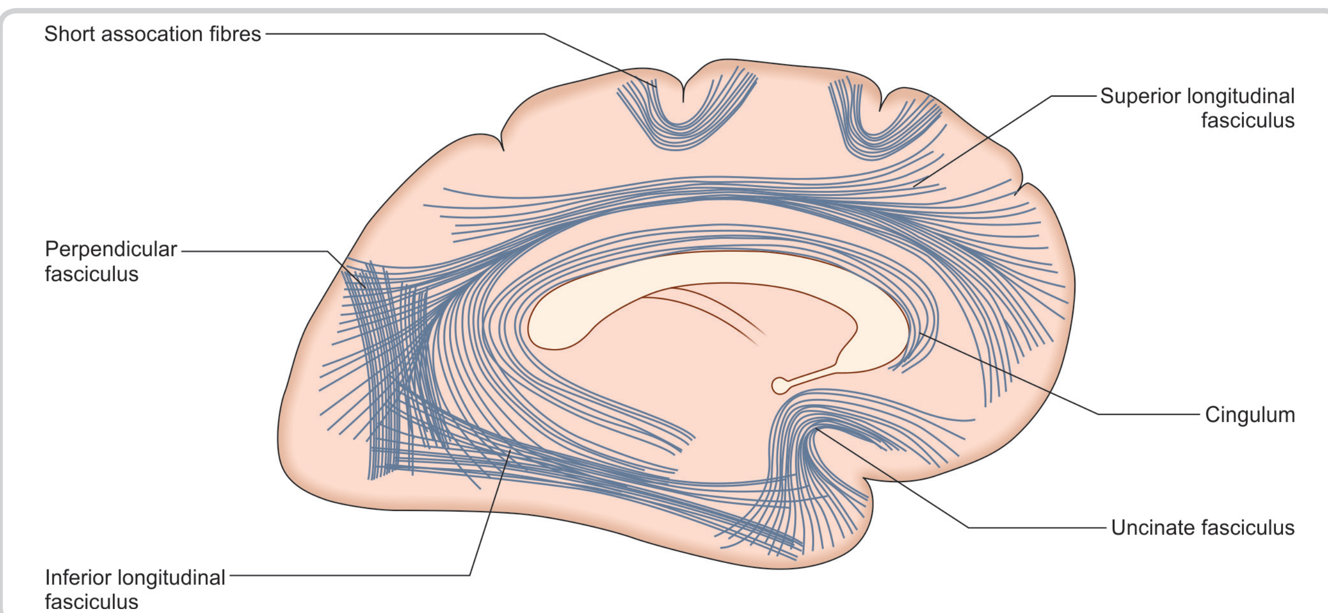

Figure 14.1: Schematic diagram to show bundles of fibres present within the cerebral hemisphere

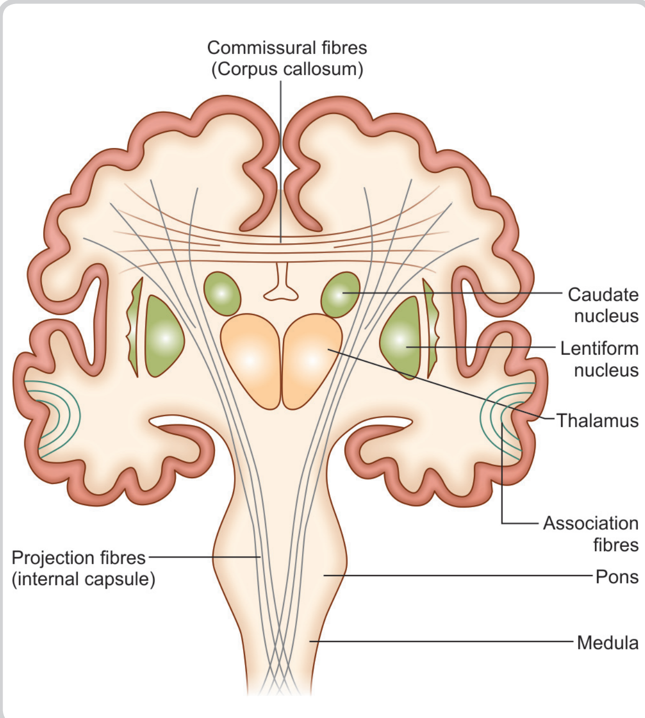

Figure 14.2: Coronal section of the brain showing association, commissural, and projection fibres

is a bundle of axons that forms part of the superior longitudinal fasciculus that connects temporal lobe and the frontal lobe. Thus, it connects the sensory and motor speech areas to each other in the dominant hemisphere).

- The ***inferior longitudinal fasciculus*** connects the occipital lobe to the temporal lobe.
- The ***fronto-occipital fasciculus*** connects frontal to occipital and temporal lobes. It is lateral to caudate nucleus, lies deep to superior longitudinal fasciculus and is separated from it by corona radiata.
- The ***perpendicular fasciculus*** connects the parietal lobe to the occipital lobe and the posterior part of temporal lobe.

COMMISSURAL FIBRES

The commissural fibres cross the midline and connect the identical parts of the two hemispheres.

Note: All fibres crossing from one side of the brain or spinal cord to the opposite side are not commissural fibres. When fibres originating in a mass of grey matter in one half of the central nervous system (CNS) end in some other mass of grey matter in the opposite half, they are referred to as ***decussating fibres,*** and the sites where such crossings take place are referred to as ***decussations.***

Examples of Commissural Fibres

- The ***corpus callosum*** is the largest commissure of the brain.
- The ***anterior commissure*** connects the right and left temporal lobes. It is of the shape of a cupid's bow. It crosses the midline in the upper part of the lamina terminalis anterior to the columns of fornix. Its fibres divide into anterior and posterior bundles. The anterior bundle connects the anterior perforated substance and the olfactory tracts of the two sides. The posterior bundle, at first, passes through the head of the caudate nucleus and then inclines posteriorly in the lentiform nucleus to enter the middle and inferior gyri of the temporal lobe.
- The ***posterior*** and ***habenular commissures*** are part of epithalamus and are located in the posterior part of the roof of third ventricle.
- The ***hippocampal commissure*** or ***commissure of fornix*** connects the hippocampus of the two sides to each other.

CORPUS CALLOSUM

This is located in the floor of the median longitudinal fissure (Figures 14.3 and 14.4).

Parts

The corpus callosum consists of four parts. Its anterior end is called the ***genu***, the central part is the ***trunk*** and the posterior bulbous part forms the ***splenium***. The fourth part is the ***rostrum***, which is the prolongation from the genu to the upper end of lamina terminalis (Figure 14.5).

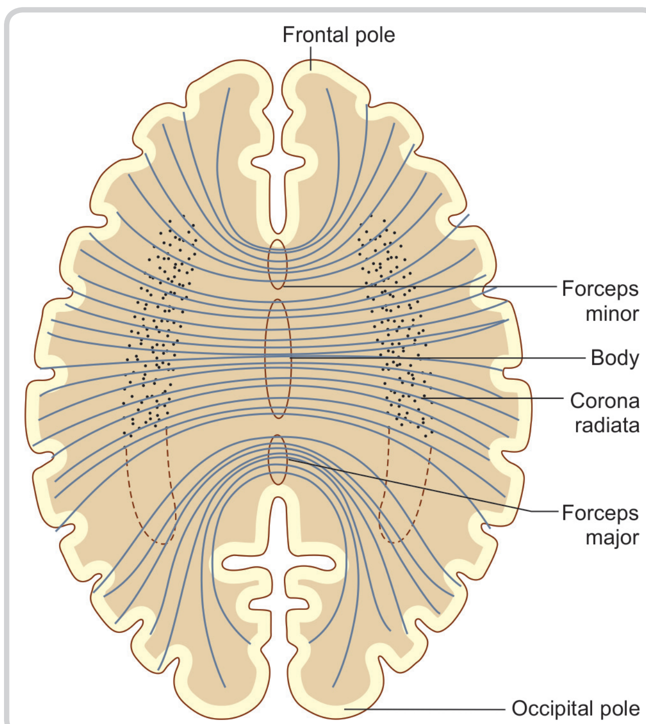

Figure 14.3: Medial sagittal and transverse sections of the cerebrum, viewed from above, showing the different parts of corpus callosum

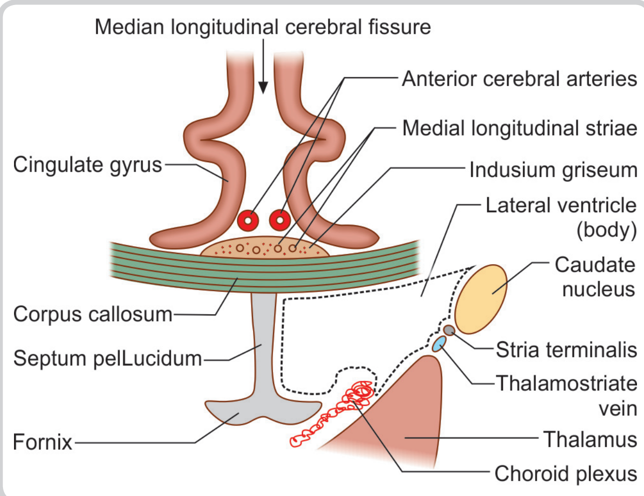

Figure 14.4: Schematic diagram to show relations of the corpus callosum

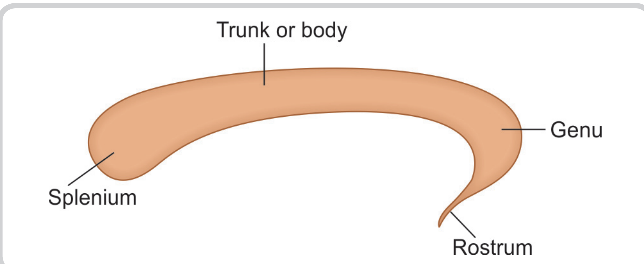

Figure 14.5: Parts of corpus callosum

Relations

- The superior aspect of the corpus callosum is covered with ***indusium griseum***, in which medial and lateral longitudinal striae are embedded. The indusium griseum is the rudimentary grey matter of dorsal hippocampus.
- Transverse fissure is located between the splenium and the superior colliculi and pineal gland. It gives passage to the tela choroidea of third and lateral ventricles. The posterior choroidal arteries enter the fissure and the internal cerebral veins leave it and unite to form the great cerebral vein beneath the splenium.
- The anterior and superior aspects of the corpus callosum are in close relation to the anterior cerebral vessels.
- The inferior aspect of the corpus callosum gives attachment to the septum pellucidum, anteriorly and the fornix, posteriorly.
- The rostrum and genu form the boundaries of the anterior horn, and the trunk forms the roof of the central part of the lateral ventricle.

Connections of Corpus Callosum

The fibres of the corpus callosum interconnect the corresponding parts of the right and left hemispheres.

- The fibres passing through the rostrum connect the orbital surfaces of the frontal lobes.
- The fibres passing through the genu interconnect the two frontal lobes by means of a fork-like bundle of fibres called ***forceps minor*** (Figure 14.3).
- The fibres passing through the splenium interconnect the occipital lobes by means of a fork like bundle of fibres called ***forceps major*** (Figure 14.3). The forceps major bulges into the medial wall of the posterior horn of lateral ventricle to give rise to an elevation called the ***bulb*** of the posterior horn.
- A large number of fibres from the trunk run transversely to intersect with the fibres of the corona radiata. Some fibres of the trunk and adjacent splenium, which do not intersect with corona radiata, are known as the ***tapetum***. The tapetum is closely related to the inferior horn and posterior horn of lateral ventricle.

Note: The fibres passing through the corpus callosum generally interconnect corresponding regions of the entire neocortex of the right and left sides. However, some important exceptions are now known.

- The greater parts of the visual areas are not interconnected. Only those parts of visual areas that receive impulses from a narrow strip along the vertical meridian of the retina are interconnected. The band of cortex concerned lies at the junction of areas 17 and 18. Similar bands are also present in relation to other visual areas.
- The parts of the sensorimotor areas (SI and SII) concerned with the hands and feet are not interconnected.

Note: The various regions to which most parts of the cerebral cortex are connected are shown in Figure 14.6.

Arterial Supply

The rostrum, genu and body of corpus callosum receive bilateral branches from anterior cerebral artery. The splenium receives branches from the posterior cerebral arteries.

Clinical Correlation

The corpus callosum can be congenitally absent. As the two cerebral hemispheres are not connected, there is a ***split brain***. If one hand is trained to perform an act the other hand may not be able to do so.

PROJECTION FIBRES

The projection fibres connect the cerebral cortex to other regions of central nervous system below it by ***corticopetal*** or ascending and ***corticofugal*** or descending fibres.

Examples of Projection Fibres

- The corona radiata (Figure 14.7) is a mass of white matter composed of the projection fibres, which converge from the cerebral cortex to the internal capsule and fan out from the internal capsule towards the cortex.

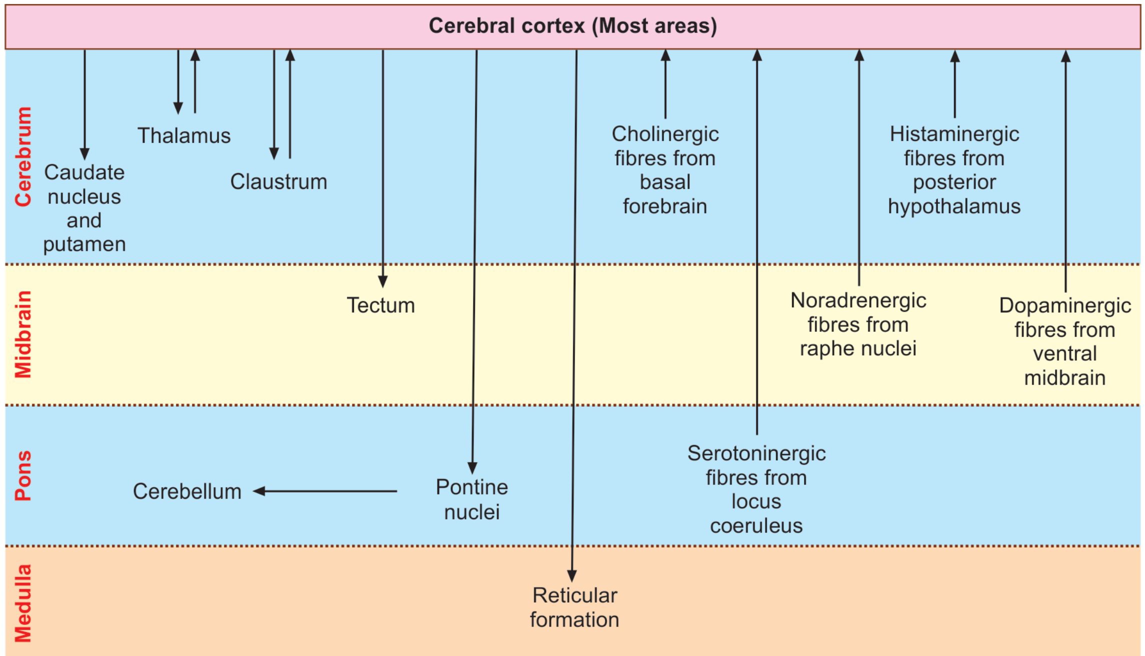

Figure 14.6: Scheme to show the regions to which most parts of the cerebral cortex are connected

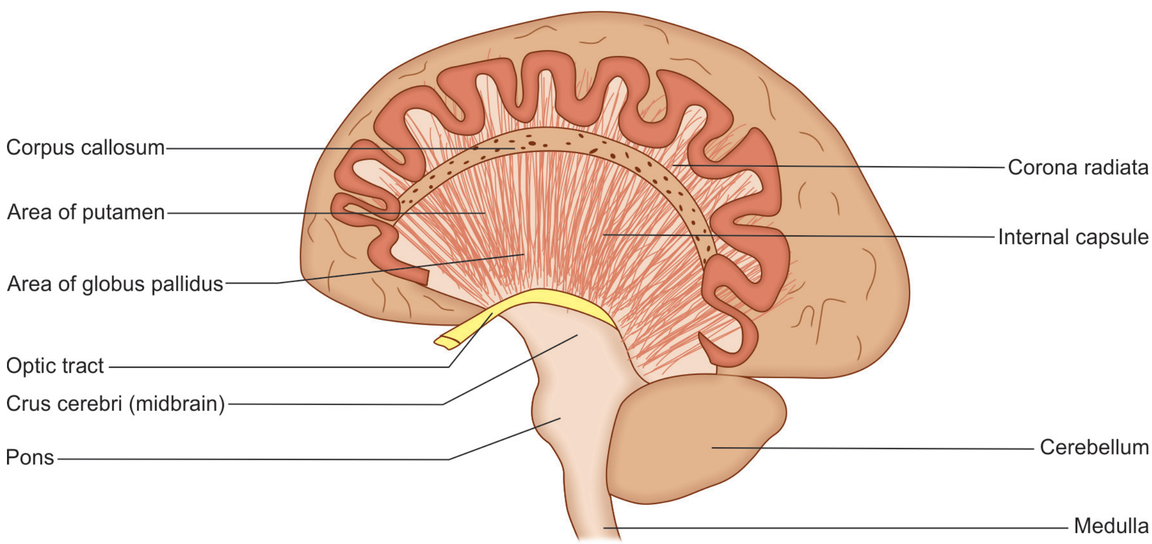

Figure 14.7: Schematic diagram to show projection fibres (corona radiata and internal capsule)

- The internal capsule transmits the projection fibres like corticospinal, corticonuclear, and corticopontine fibres. These fibres arise in the cerebral cortex and terminate on the lower neurons (like anterior horn cells, cranial nerve nuclei in brainstem and pontine nuclei). The internal capsule also gives passage to thalamic radiations (comprising to and fro connections between cerebral cortex and thalamic nuclei).
- The fornix is composed of projection fibres, which take origin from the hippocampus. The fibres in the fornix are connected to the neurons of the mammillary body.

INTERNAL CAPSULE

A large number of nerve fibres project from the cerebral cortex to interconnect with subcortical centres in the brainstem and spinal cord and with the thalamus. This compact bundle of fibres is collectively called the ***internal capsule***.

Relations

These fibres fan out cranially to form corona radiata and condense caudally to form the crus cerebri of the midbrain (Figure 14.7). Most of these fibres pass through the interval

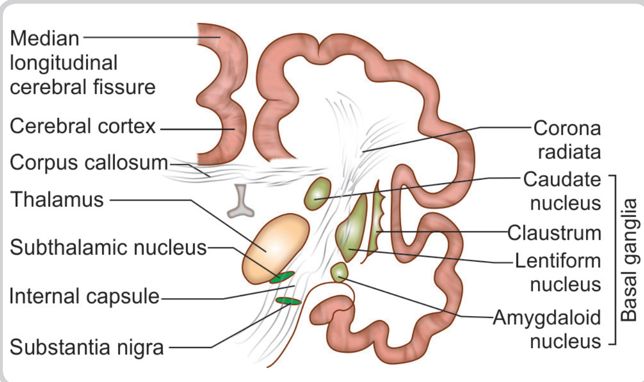

Figure 14.8: Coronal section through a cerebral hemisphere to show the location of internal capsule

between the thalamus and caudate nucleus medially and the lentiform nucleus laterally (Figure 14.8). This region is called the ***internal capsule.***

Parts

The internal capsule may be divided into the following parts (Figure 14.9):

- ***Anterior limb:*** The anterior limb lies between the caudate nucleus medially and the anterior part of the lentiform nucleus laterally.
- ***Posterior limb:*** The posterior limb lies between the thalamus medially and the posterior part of the lentiform nucleus laterally.
- ***Genu:*** In transverse section through the cerebral hemisphere, the anterior and posterior limbs of the internal capsule meet at an angle open outwards. This angle is called the ***genu*** (***genu*** = ***bend***).
- ***Retrolentiform part:*** Some fibres of the internal capsule lie behind the posterior end of the lentiform nucleus. They constitute its retrolentiform part.
- ***Sublentiform part:*** Some other fibres pass below the lentiform nucleus (and not medial to it). These fibres constitute the sublentiform part of the internal capsule.

Various parts of the internal capsule consist of large number of fibres. The fibres passing through the capsule may be ascending (to the cerebral cortex) or descending (from the cortex). The arrangement of fibres is easily remembered, if it is realized that any group of fibres within the capsule ***takes the most direct path*** to its destination. Thus, fibres to and from the anterior part of the frontal lobe pass through the anterior limb of the internal capsule. The fibres to and from the posterior part of the frontal lobe and from the greater part of the parietal lobe occupy the genu and posterior limb of the capsule. Fibres to and from the temporal lobe occupy the sublentiform part, while those to and from the occipital lobe pass through the retrolentiform part. Some fibres from the lowest parts of the parietal lobe accompany the temporal fibres through the sublentiform part.

ASCENDING FIBRES (SENSORY FIBRES)

These are ***predominantly thalamocortical fibres,*** which go from the thalamus to all parts of the cerebral cortex (Figures 14.10 and 14.11).

- ***Anterior thalamic radiation:*** Fibres to the frontal lobe constitute the anterior thalamic radiation (or ***frontal thalamic peduncle***). They pass through the anterior limb of the internal capsule. The fibres arise mainly from the medial and anterior nuclei of the thalamus. The anterior thalamic radiation also carries fibres from the hypothalamus and limbic structures to the frontal cortex.

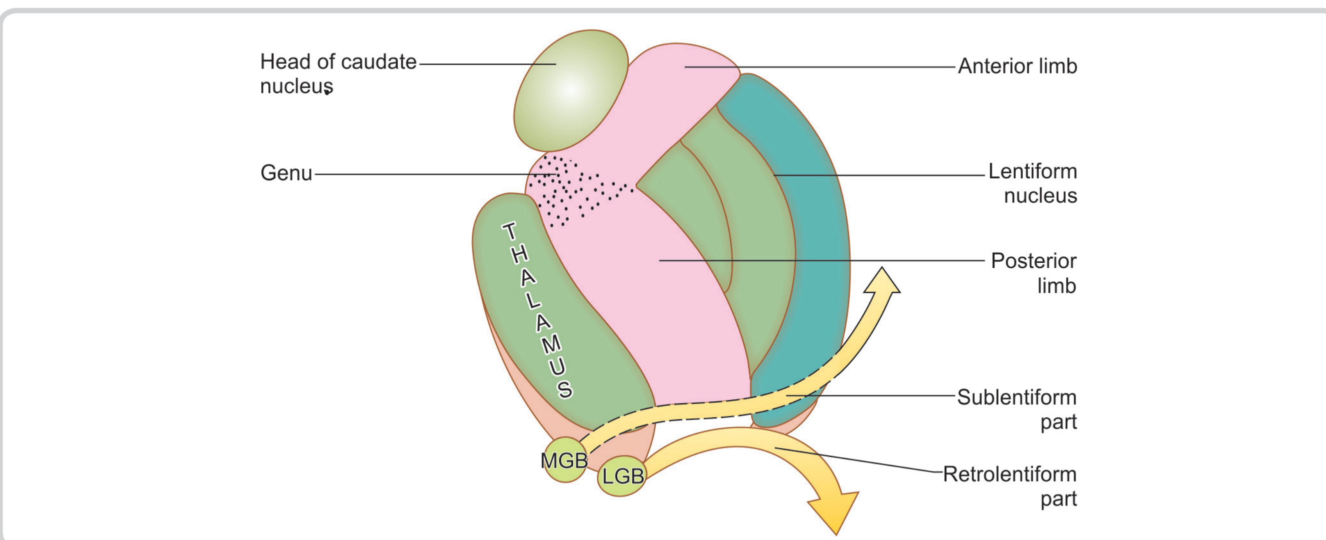

Figure 14.9: Scheme to show the subdivisions of the internal capsule

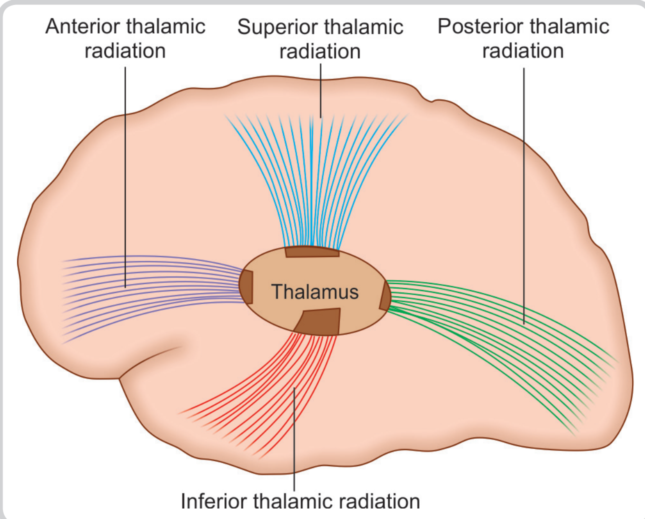

Figure 14.10: Schematic diagram to show ascending fibres passing through internal capsule–thalamic radiations

- ***Superior thalamic radiation:*** Fibres traveling from the ventral posterior nuclei of the thalamus to the somatosensory area (in the postcentral gyrus) constitute the superior thalamic radiation (or the ***superior or dorsal thalamic peduncle***). These fibres occupy the genu and posterior limb of the capsule. It should be noted that these fibres are third-order sensory neurons responsible for conveying somesthetic sensations to the cerebral cortex. The superior thalamic radiation also contains some fibres that go from the thalamus to parts of the frontal and parietal lobes adjoining the postcentral gyrus.
- ***Posterior thalamic radiation:*** Fibres from the thalamus to the occipital lobe constitute the posterior thalamic radiation (or the ***posterior or caudal thalamic peduncle***). This includes the ***optic radiation*** from the lateral geniculate body to the visual cortex. These radiations lie in the retrolentiform part of the internal capsule. The retrolentiform part also contains some fibres passing from the thalamus to the posterior part of the parietal lobe.
- ***Inferior thalamic radiation:*** Fibres from the thalamus to the temporal lobe constitute the inferior thalamic radiation (or ***ventral thalamic peduncle***). It includes the ***auditory radiation*** from the medial geniculate body to the acoustic area of the cerebral cortex. These fibres pass through the sublentiform part of the internal capsule.

DESCENDING FIBRES (MOTOR FIBRES)

The descending fibres are the projection fibres and are also called centrifugal fibres (Figure 14.11).

- ***Corticopontine fibres:*** They originate from all four lobes of cerebral cortex and are named according to the lobe from which they arise:
  - ***Frontopontine fibres*** are the most numerous. They pass through the anterior limb, genu, and posterior limb of the internal capsule.
  - ***Parietopontine fibres*** pass mainly through the retrolentiform part. Some fibres pass through the sublentiform part.
  - ***Temporopontine fibres*** pass through the sublentiform part (Figure 14.12).
  - ***Occipitopontine fibres*** pass through the retrolentiform part.

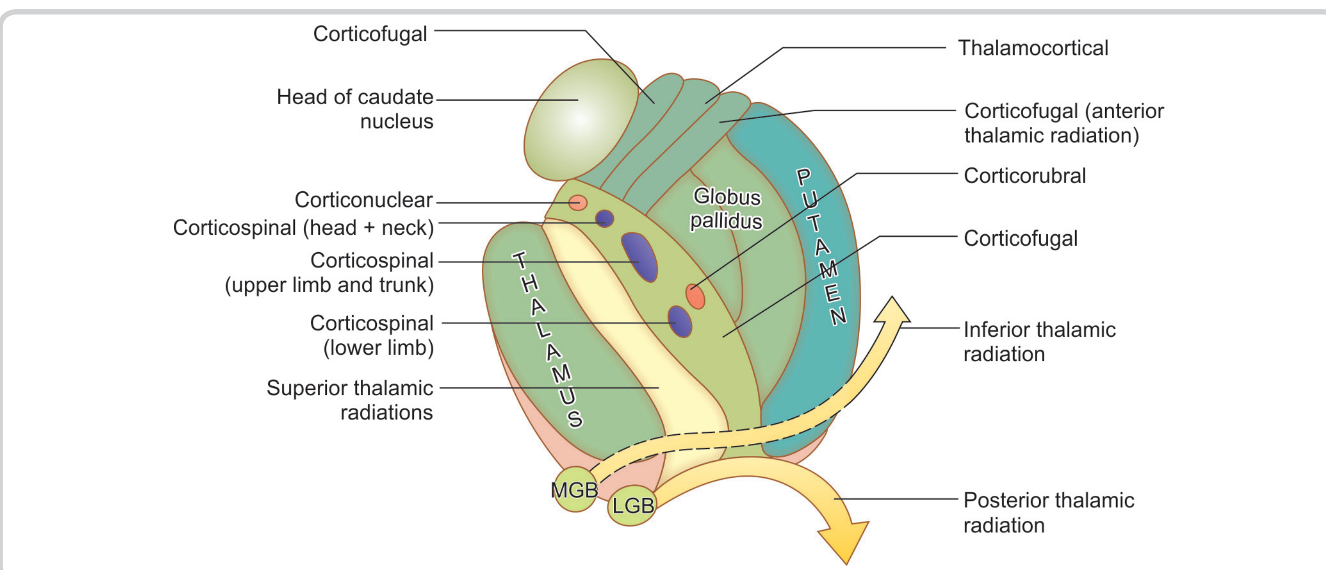

Figure 14.11: Scheme to show the subdivisions of the internal capsule (MGB & LGB) – medial and lateral geniculate bodies

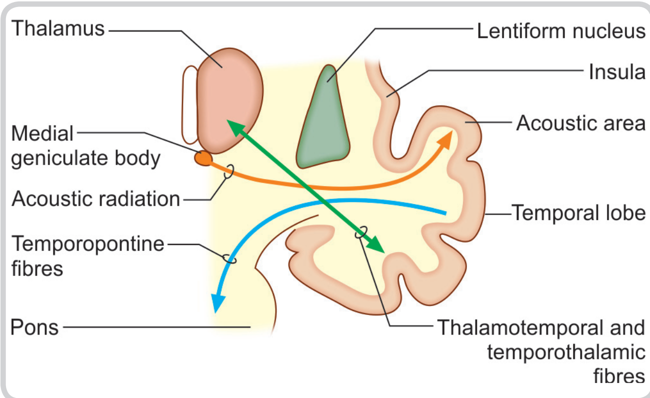

Figure 14.12: Scheme to show the fibres passing through the sublentiform part of the internal capsule

- ***Pyramidal fibres (corticospinal and corticonuclear fibres):***
  - ***Corticonuclear fibres*** (for motor cranial nerve nuclei) pass through the genu of the internal capsule.
  - ***Corticospinal fibres*** form several discrete bundles in the posterior limb of the capsule. The fibres for the upper limb are most anterior followed (in that order) by fibres for the trunk and lower limb.
- ***Corticothalamic fibres:*** These pass from various parts of the cerebral cortex to the thalamus. They form part of the thalamic radiations described above
- ***Extrapyramidal fibres:***
  - ***Corticostriate fibres*** originating from all parts of cerebral cortex and terminating in caudate nucleus and putamen
  - ***Corticorubral fibres*** originating from the motor areas of the frontal lobe and terminating in the red nucleus
  - ***Corticoreticular fibres*** beginning from the motor cortex and the parietal lobes and terminating in reticular nuclei.

A summary of the various ascending and descending fibres passing through different parts of internal capsule are given in Table 14.1.

ARTERIAL SUPPLY OF INTERNAL CAPSULE

The main arteries supplying the internal capsule are the medial and lateral striate branches of the middle cerebral artery, the recurrent branch of the anterior cerebral, and the anterior choroidal artery. The internal capsule may also receive direct branches from the internal carotid artery and branches from the posterior communicating artery (Figure 14.13).

- The ***upper parts*** of the anterior limb, the genu and the posterior limb are supplied by the medial and lateral striate branches of the middle cerebral artery.

  One of the lateral striate branches is larger and more frequently ruptured. It is often called ***Charcot's artery of cerebral hemorrhage.*** It enters through the anterior

Table 14.1 | Fibres in Internal Capsule

Part	Motor fibres	Sensory fibres
Anterior limb	• Frontopontine fibres • Frontothalamic fibres	Anterior thalamic radiation
Genu	• Frontopontine fibres • Corticonuclear fibres • Corticoreticular fibres • Parietothalamic fibres	Superior thalamic radiation
Posterior limb	• Frontopontine fibres • Corticospinal fibres • Corticorubral fibres • Corticoreticular fibres • Parietothalamic fibres	Superior thalamic radiation
Retrolentiform part	• Parietopontine fibres • Occipitopontine fibres • Corticotectal fibres • Occipitothalamic fibres	Posterior thalamic radiation (optic radiation)
Sublentiform part	• Parietopontine fibres • Temporopontine fibres • Temporothalamic fibres	• Inferior thalamic radiation • Acoustic radiation

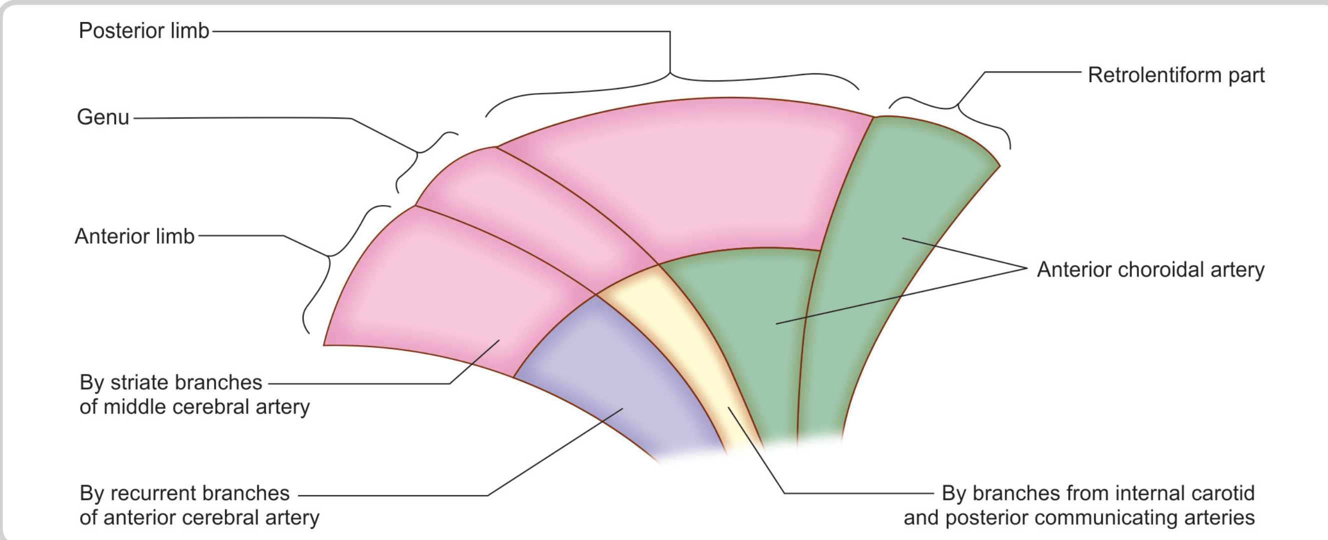

Figure 14.13: Scheme to show the arterial supply of the internal capsule

perforated substance and supplies the posterior limb of the internal capsule.

- The ***lower parts*** of these regions are supplied as follows:
  - The lower part of the anterior limb is supplied by the medial striate artery (also called ***recurrent artery of Heubner***), branch of the anterior cerebral artery.
  - The lower part of the genu is supplied by direct branches from the internal carotid and from the posterior communicating artery.
  - The lower part of the posterior limb is supplied by the anterior choroidal artery and striate branch of posterior cerebral artery.
- The retrolentiform part of the internal capsule is supplied by the anterior choroidal artery.
- The sublentiform part is probably supplied by the anterior choroidal artery.

Clinical Correlation

The arterial supply of internal capsule is of great clinical significance. Any occlusion of blood vessel supplying the internal capsule can lead to a potentially serious clinical outcome.

A lesion in the internal capsule is most likely to result from thrombosis or rupture of one of the arteries supplying the capsule. The artery most often involved is Charcot's artery of cerebral hemorrhage.

Thrombosis in an artery supplying the internal capsule (cerebral thrombosis) leads to a stroke that results in hemiplegia. The opposite side of the body is affected. As the tracts passing through the internal capsule are closely packed, even a small lesion can cause extensive paralysis. Sensations can also be lost. Reflexes are exaggerated as in a typical upper motor neuron paralysis.

Multiple Choice Questions

1. The cortical areas of the same cerebral hemisphere are connected by
   A. Internal capsule
   B. Association fibres
   C. Corona radiata
   D. Commissural fibres
2. Internal capsule is an example of which type of white fibres?
   A. Long association
   B. Projection
   C. Commissural
   D. Short association
3. The upper surface of the corpus callosum is related to
   A. Indusium griseum
   B. Arcuate fasciculus
   C. Fornix
   D. Locus coeruleus
4. The fibres forming corona radiata intersect with the fibres of
   A. Anterior commissure
   B. Cingulum
   C. Inferior longitudinal fasciculus
   D. Corpus callosum
5. The structure related laterally to the internal capsule is
   A. Lentiform nucleus
   B. Thalamus
   C. Caudate nucleus
   D. Amygdaloid body
6. The posterior limb of the internal capsule contains
   A. Corticospinal fibres
   B. Corticorubral fibres
   C. Superior thalamic radiation
   D. All of the above
7. Which of the following parts of internal capsule lies between the head of the caudate nucleus and the lentiform nucleus?
   A. Genu
   B. Anterior limb
   C. Posterior limb
   D. Sublentiform part
8. Which part of the internal capsule is supplied by Charcot's artery of cerebral hemorrhage?
   A. Anterior limb
   B. Genu
   C. Posterior limb
   D. Sublentiform part
9. Anterior choroidal artery supplies which part of internal capsule?
   A. Anterior limb
   B. Genu
   C. Posterior limb
   D. Retrolentiform part

Answers

1. B **2.** B **3.** A **4.** D **5.** A **6.** D **7.** B **8.** C **9.** D

Chapter 15

Basal Nuclei (Basal Ganglia)

Specific Learning Objectives

At the end of learning, the student shall be able to:
- Describe the components, basic connections and functions of basal nuclei
- Explain the anatomical basis of Parkinson's disease, chorea, athetosis and ballismus

INTRODUCTION

The basal nuclei (or basal ganglia) are large masses of grey matter situated in the cerebral hemispheres.

Anatomically, the basal nuclei include large subcortical masses of grey matter located within each cerebral hemisphere developing from telencephalon. They include (Figure 15.1):
- ***Caudate nucleus***
- ***Lentiform nucleus***, which consists of two functionally distinct parts, the ***putamen*** and the ***globus pallidus***
- ***Amygdaloid nuclear complex***
- ***Claustrum***

The caudate nucleus and the lentiform nucleus together constitute the ***corpus striatum*** (Figure 15.2). This consists of two functionally distinct parts. The caudate nucleus and the putamen form one unit called the ***striatum (***also known as ***neostriatum),*** while the globus pallidus forms the other unit, the ***pallidum (***also known as ***paleostriatum).*** Phylogenetically, ***amygdaloid nuclear complex*** and ***claustrum*** are considered as ***archistriatum***.

Functionally, the basal nuclei comprises of structures, the lesion of which produces ***dyskinesias*** (abnormal involuntary purposeless movement). The structures included are
- ***Corpus striatum***
- The ***subthalamic nucleus*** (which is of diencephalic origin) is very closely linked to the basal nuclei and is regarded as belonging to this group.
- The ***substantia nigra*** (midbrain) is also closely linked, functionally, to the basal nuclei.
- Some masses of grey matter found just below the corpus striatum (near the anterior perforated substance) are described as the ***ventral striatum***. The part of the globus pallidus, which lies below the level of the anterior commissure, is designated as the ***ventral pallidum***.

CAUDATE NUCLEUS

The caudate nucleus is a C-shaped mass of grey matter (Figures 15.3 and 15.4). It consists of a large head, body,

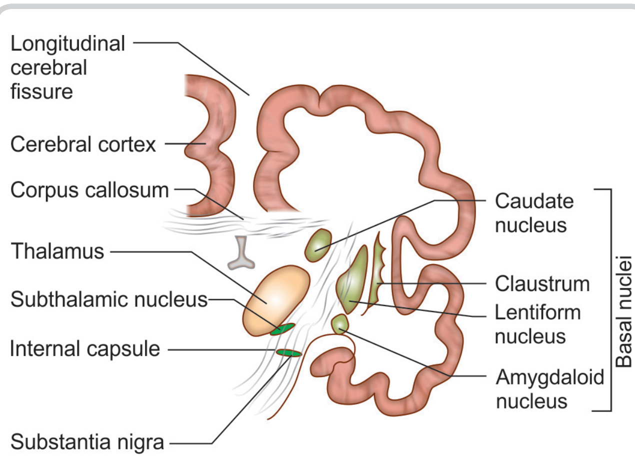

Figure 15.1: Coronal hemisection of cerebrum showing basal nuclei

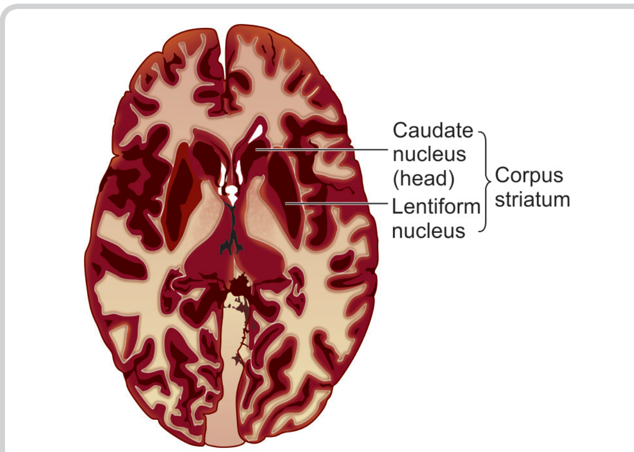

Figure 15.2: Plastinated horizontal section of the brain through interventricular foramen showing corpus striatum. Compare this section with Figure 15.4

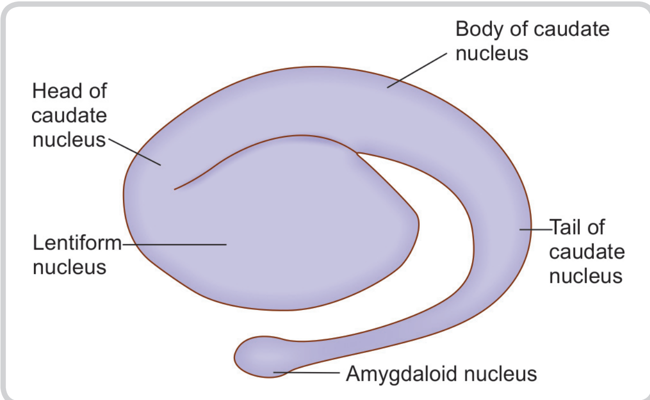

Figure 15.3: Corpus striatum viewed from the lateral aspect

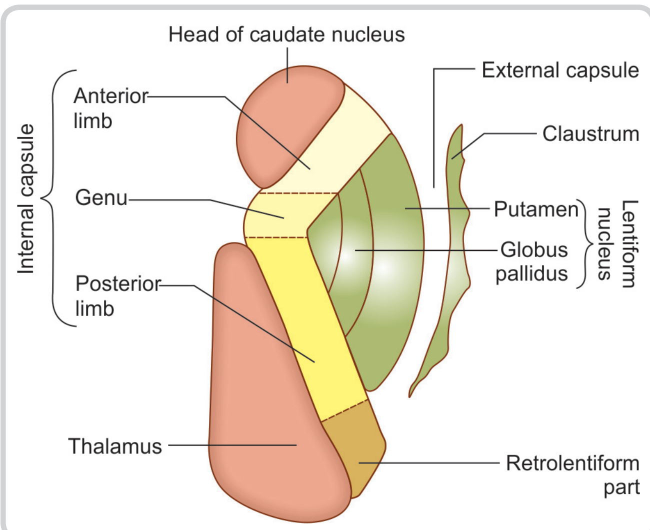

Figure 15.4: Horizontal section of the cerebral hemisphere showing corpus striatum, thalamus, claustrum, and internal capsule

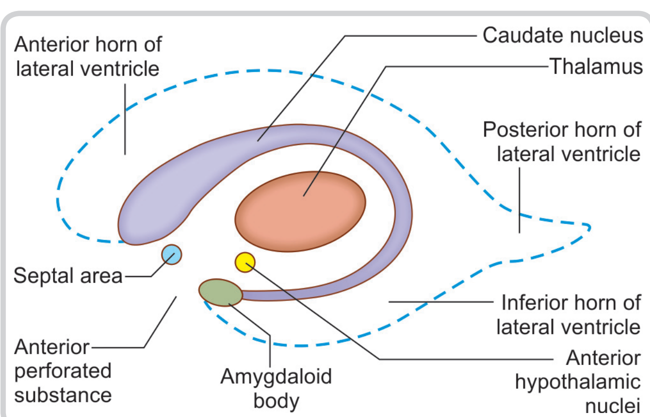

Figure 15.5: Relations of caudate nucleus with the cavity of the fourth ventricle and thalamus

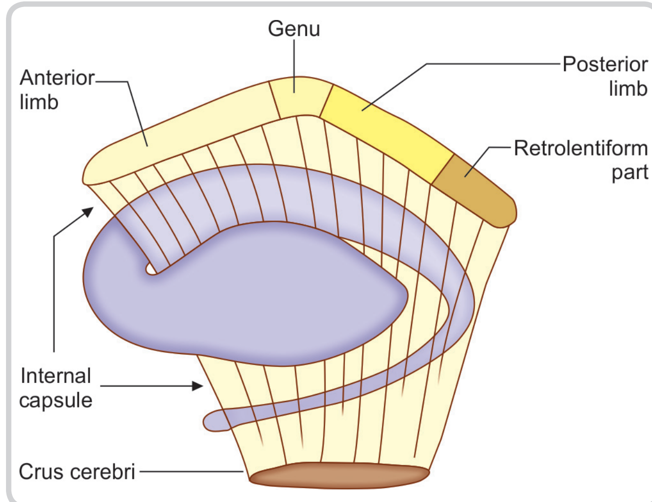

Figure 15.6: Relations of the corpus striatum to the internal capsule

and thin tail. The nucleus is intimately related to the lateral ventricle (Figure 15.5). The head of the nucleus bulges into the anterior horn of the ventricle and forms the greater part of its floor (Figure 17.3). The body of the nucleus lies in the floor of the central part and the tail in the roof of the inferior horn of the ventricle. The anterior part of the head of the caudate nucleus is fused, inferiorly, with the lentiform nucleus. This region of fusion is referred to as the ***fundus striati***. The fundus striati is continuous, inferiorly, with the anterior perforated substance. The anterior end of the tail of the caudate nucleus ends by becoming continuous with the lentiform nucleus. It lies in close relation to the amygdaloid complex.

The body of the caudate nucleus is related medially to the thalamus and laterally to the internal capsule, which separates it from the lentiform nucleus (Figure 15.1).

Relations of the corpus striatum to the internal capsule is shown in Figure 15.6.

LENTIFORM NUCLEUS

The lentiform nucleus appears triangular (or wedge-shaped) in the coronal section.

Relations

The lentiform nucleus lies lateral to the internal capsule. Laterally, it is separated from the claustrum by fibres of the external capsule (Figure 15.4). (Note that these capsules are so called because they appear, to the naked eyes, to form a covering or capsule for the lentiform nucleus). Superiorly, the lentiform nucleus is related to the corona radiata and inferiorly, to the sublentiform part of the internal capsule.

Parts

It is divided by a thin lamina of white matter, known as external medullary lamina, into a lateral part, the ***putamen*** and a medial part, the ***globus pallidus.*** The globus pallidus is further subdivided into medial and lateral (or internal and external) segments, by the internal medullary lamina.

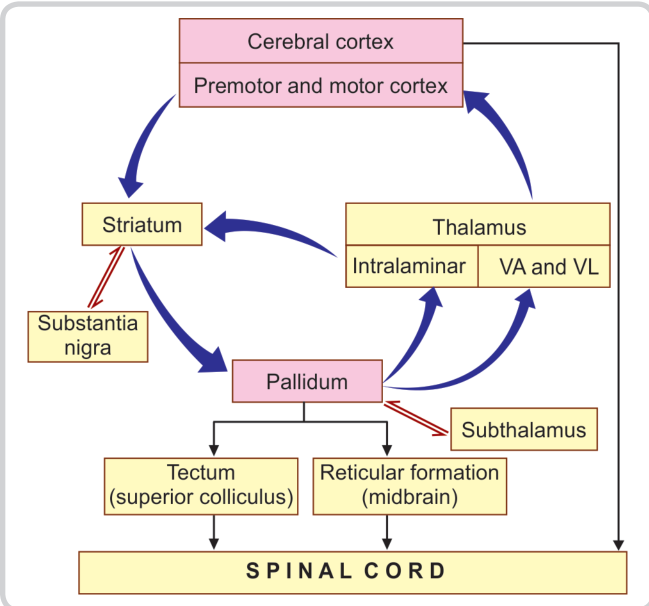

Figure 15.7: Diagram showing connections of basal nuclei. Shown in red colour is the cortical-basal nuclei-thalamic-cortical loop

CONNECTIONS OF CORPUS STRIATUM

Afferent Connections

The striatum (caudate and lentiform nuclei) receive afferents from the following (Figure 15.7):

- The entire cerebral cortex via ***corticostriate*** fibres. These fibres are glutamatergic
- The intralaminar nuclei of the thalamus via ***thalamo-striate*** fibres
- The pars compacta of the substantia nigra via ***nigrostriate*** fibres. These fibres are dopaminergic. (Some dopaminergic fibres arise from the retrorubral nuclei lying behind the red nucleus)
- Noradrenergic fibres are received from the locus coeruleus
- Serotoninergic fibres are received from the raphe nuclei (in the reticular formation of the midbrain).

The afferents from the cerebral cortex and from the thalamus provide the striatum with various modalities of sensory information (other than olfactory).

Efferent Connections

The main output of the striatum is concentrated upon the pallidum and on the substantia nigra (pars reticularis). The outflow from globus pallidus forms four separate bundles (Figure 12.28).

- ***Fasciculus lenticularis*** arises from the inner segment of the globus pallidus and enters the subthalamic region.
- ***Ansa lenticularis*** arises from both the inner and outer segments of the globus pallidus and enters the subthalamic region where it meets the dentato-rubrothalamic fibres and the fasciculus lenticularis. The union of the three tracts is called the ***fasciculus thalamicus***, which terminates in the ventralis anterior (VA), ventralis lateral (VL), and centromedian nuclei of thalamus.
- ***Subthalamic fasciculus*** consists of reciprocal connections between the globus pallidus and nucleus subthalamicus.
- Some fibres from globus pallidus also pass to the substantia nigra (***pallidonigral fibres***).

Functions of Corpus Striatum

- The corpus striatum mediates enormous number of automatic activities involved in normal motor functions. For example, the maintenance of erect posture when sitting or standing, or swinging of arms during walking.
- It helps in smoothening the voluntary motor activity of the body.

Claustrum

This is a thin lamina of grey matter that lies lateral to the lentiform nucleus (Figure 15.1). It is separated from the latter by fibres of the external capsule (Figure 15.4). Laterally, it is separated by a thin layer of white matter from the cortex of the insula. Its connections and functions are unknown.

Amygdaloid Nuclear Complex

This complex (also called the amygdaloid body, amygdala) lies in the temporal lobe of the cerebral hemisphere, close to the temporal pole. It lies deep to the uncus and is related to the anterior end of the inferior horn of the lateral ventricle.

Substantia Nigra

Substantia nigra is a large motor nucleus present in the mid-brain. The nucleus consists of two parts—(1) pars reticulata and (2) pars compacta (Figure 15.8). Pars reticulata is related functionally to the internal part of globus pallidus.

Connections of Substantia Nigra

The ***pars compacta*** of the substantia nigra sends a dopaminergic projection to the striatum (Figure 15.9). A projection from the striatum ends in the pars reticularis of the substantia nigra. This part also receives fibres from the

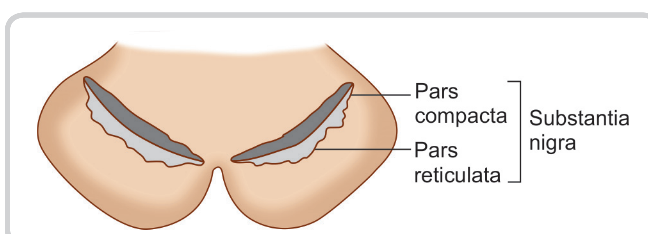

Figure 15.8: Transverse section of midbrain showing parts of substantia nigra

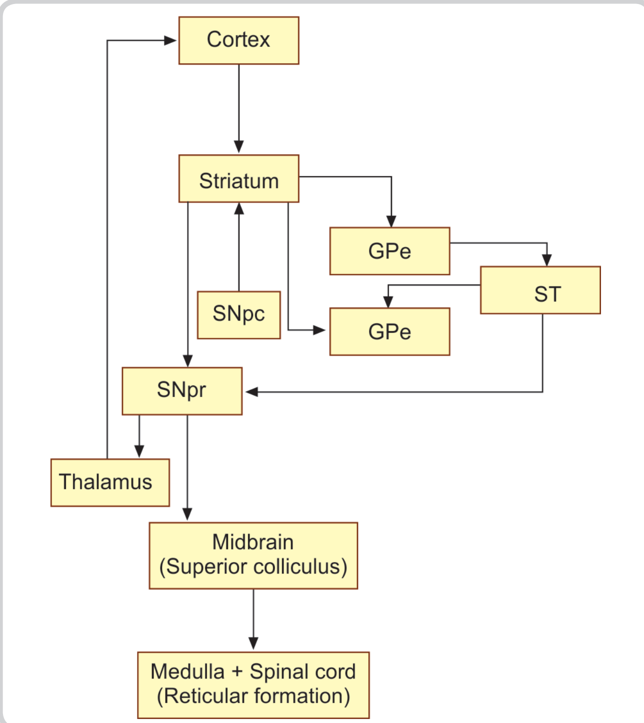

Figure 15.9: Scheme to show the connections of the substantia nigra
(SNpc, Substantia nigra pars compacta; SNpr, Substantia nigra pars reticulata; ST, Subthalamic nucleus; GPe, Globus pallidus external segment; GPi, Globus pallidus internal segment)

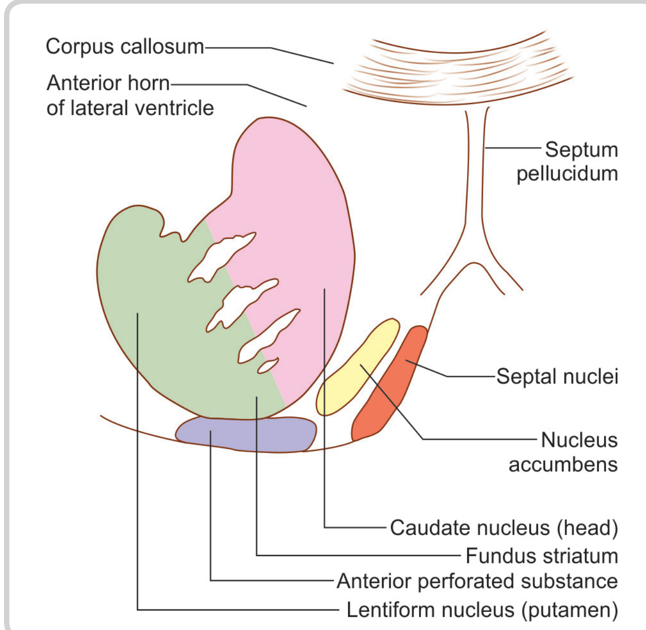

Figure 15.10: Coronal section passing through the anterior part of corpus striatum

pallidum directly or after relay in the subthalamic nucleus or in the pedunculopontine nucleus.

The ***pars reticularis*** projects to the (middle part) ventral lateral nucleus of the thalamus. These impulses are relayed to cingulate and prefrontal areas of the cerebral cortex. Other efferents of the pars reticularis reach the superior colliculus. They are relayed from there to the reticular formation of the medulla and to the spinal cord. These regions also receive fibres descending from the pedunculopontine nucleus.

Clinical Correlation

The main connections (both afferent and efferent) of substantia nigra are with the striatum (i.e., caudate nucleus and putamen). Dopamine produced by neurons in the substantia nigra (pars compacta) passes along their axons to the striatum (***mesostriatal dopamine system***). Dopamine is much reduced in patients with a disease called ***parkinsonism,*** in which there is a degeneration of the striatum.

In summary,

- The cerebral cortex sends impulses to the corpus striatum through the thalamus, which forms a direct feedback loop.
- The substantia nigra, the subthalamic nucleus, and the pedunculopontine nucleus are integrated with the basal ganglia to form an indirect feedback loop to the cerebral cortex through the thalamus.
- Descending fibres from the basal ganglia influence the superior colliculus, the reticular formation of the medulla, and thus, the motor neurons of the spinal cord (Figure 15.7).

VENTRAL STRIATUM AND PALLIDUM

On the basis of recent investigations, some masses of grey matter lying in the region of the anterior perforated substance are now described as the ventral striatum. In Figure 15.10, we see the anterior part of the caudate and lentiform nuclei. Inferiorly, the two nuclei fuse to form the ***fundus striati***. Immediately below the fundus striati, there is the olfactory tubercle (in the anterior perforated substance). More medially, there is a mass of grey matter called the ***nucleus accumbens***. Note that this nucleus is closely related to the caudate nucleus (superolaterally) and to the septal nuclei medially. The ***ventral striatum*** consists of the nucleus accumbens and the olfactory tubercle.

Thus

- Dorsal striatum includes caudate nucleus and putamen
- Ventral striatum includes nucleus accumbens and olfactory tubercle
- Dorsal pallidum is formed by globus pallidus
- Ventral pallidum is the part below anterior commissure

A coronal section through the brain, a little posterior to the plane of Figure 15.10 is shown in Figure 15.11. Note the anterior commissure running laterally just below the head of the caudate nucleus. It cuts through the globus pallidus. The part of the globus pallidus lying inferior to

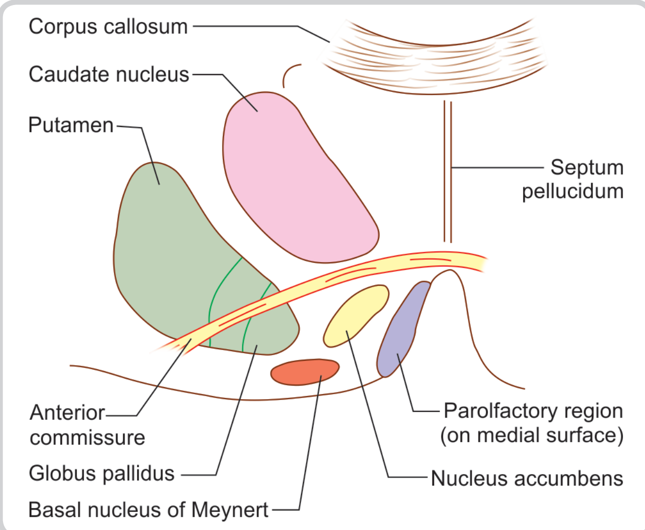

Figure 15.11: Composite diagram showing the region of the ventral thalamus. Actually, all structures shown cannot be seen in any one vertical plane

the anterior commissure is called the ***ventral pallidum***. In this figure, the position of the nucleus accumbens is shown diagrammatically; it actually lies more anteriorly.

The reason for considering the nucleus accumbens and the olfactory tubercle as parts of the striatum is that their connections are very similar to those of the main part of the striatum (or dorsal striatum).

BLOOD SUPPLY OF BASAL NUCLEI

The basal nuclei are supplied by:

- Lenticulostriate branches of middle and anterior cerebral arteries
- Anterior choroidal branch of internal carotid artery

Clinical Correlation

Abnormal movements

Various kinds of abnormal movement are seen in neurological disorders involving the basal nuclei (basal ganglia), the subthalamic nucleus and the cerebellum. Involvement of basal nucleus results in unwanted involuntary movements (***dyskinesis***) and not paralysis (kinesia; movement).

The movements could be **hyperkinetic** (rapid movements) or **hypokinetic** (slow movements, difficult to initiate movement or absent movement).

In hyperkinetic conditions the movements are excessive and abnormal. They includes ***chorea***, ***athetosis*** and ***ballism***.

- ***Chorea*** is characterized by rapid, involuntary, purposeless, dancing movements of the distal parts of the limbs
  - ***Sydenham's chorea (St vitus dance)***: Sometimes occurs as a complication of rheumatic fever. The pathology is seen in the striatum.

Contd...

  - ***Huntington's chorea***: It is an autosomal dominant degenerative disease of the striatum and cerebral cortex.
- ***Athetosis*** is characterized by continuous slow writhing movements.
- ***Ballism*** is characterized by involuntary and violent movements. In ***Hemiballism*** only one half of the body is involved. It is known to be produced by lesions in the subthalamic nucleus of the opposite side. When restricted to one limb it is ***monoballism***.

PARKINSONISM OR PARALYSIS AGITANS (SHAKING PALSY)

It is characterized by marked rigidity, which leads to a stooping posture, a slow shuffling gait, difficulty in speech, and a mask-like face (Figure 15.12). Characteristic involuntary "pill-rolling" movements of the hands are seen. The condition is believed to be due to degenerative changes in the striatum and the substantia nigra.

In patients of parkinsonism, positron emission tomography (PET) reveals deficit of dopamine in the striatum. Grafting of embryonic ventral mesencephalic tissue, which is rich in dopamine producing neurons, has been tried as a treatment of parkinsonism with limited success. Further refinements of the technique may make this a clinically valuable treatment. It has also been found that in some disorders of the striatum (for example, progressive supranuclear gaze palsy), adequate amounts of dopamine reach the striatum from the substantia nigra, but receptors for dopamine are deficient in the striatal neurons.

Figure 15.12: Parkinson's disease—resting tremors, passive rigidity and bradykinesia

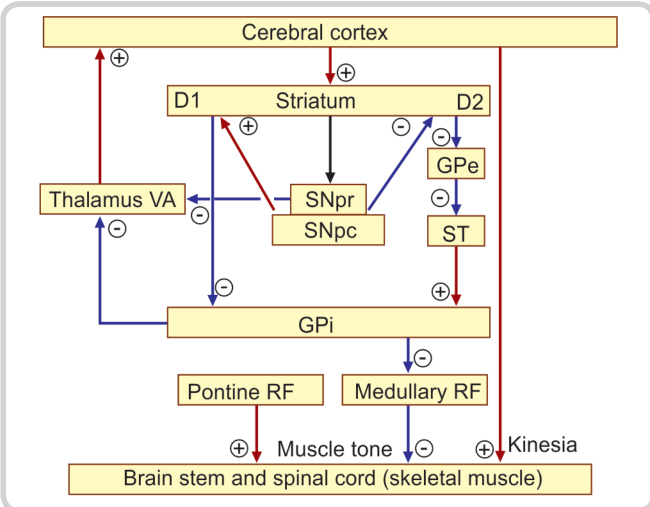

Figure 15.13: Circuitry of corpus striatum (D1 and D2, dopamine receptors; GPe, globus pallidus external segment; GPi, globus pallidus internal segment; RF, reticular formation; SNpc, substantia nigra pars compacta; SNpr, substantia nigra pars reticulate; ST, subthalamic nucleus; VA, ventral anterior nucleus)

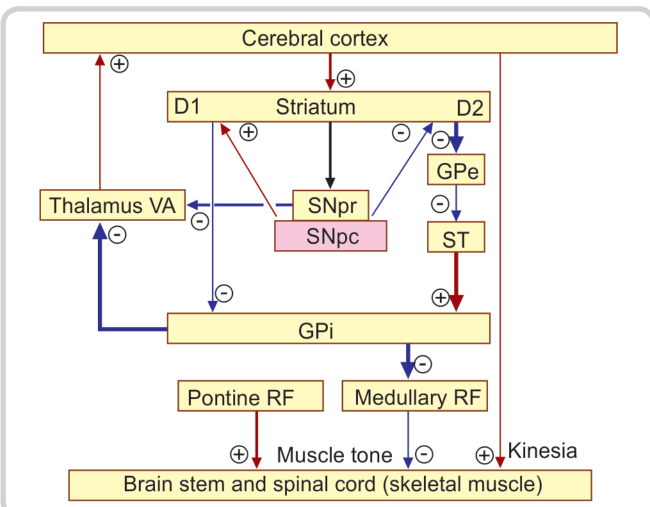

Figure 15.14: Circuitry of corpus striatum in Parkinson's disease (D1 and D2, dopamine receptors; GPe, globus pallidus external segment; GPi, globus pallidus internal segment; RF, reticular formation; SNpc, substantia nigra pars compacta; SNpr, substantia nigra pars reticulate; ST, subthalamic nucleus; VA, ventral anterior nucleus)

The following Figures (Figures 15.13, 15.14 and 15.15) explain the functional anatomy of the disorders involving the basal nuclei.

Circuitry of corpus striatum (Figure 15.13)

Starting from substantia nigra pars compacta (SNpc), nigrostriate fibres liberate dopamine at their nerve terminal. Dopamine acts as a facilitatory neurotransmitter in the striatum when the receptors of dopamine are

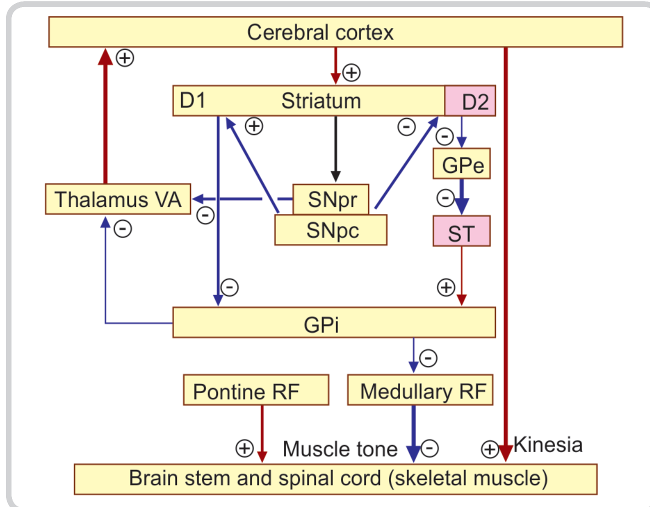

Figure 15.15: Circuitry of corpus striatum in chorea (involvement of D2 neurons) or ballismus (involvement of subthalamic nucleus) (D1 and D2, dopamine receptors; GPe, globus pallidus external segment; GPi, globus pallidus internal segment; RF, reticular formation; SNpc, substantia nigra pars compacta; SNpr, substantia nigra pars reticulate; ST, subthalamic nucleus; VA, ventral anterior nucleus)

D1; while it is an inhibitory neurotransmitter when the receptors are D2. Striatal D1 neurons inhibit globus pallidus internal segment (GPi) through a direct path; and D2 neurons facilitate GPi through an indirect path. This balances the impulses reaching the GPi.

GPi normally inhibits thalamus. Thalamus facilitates the cerebral cortex, which causes normal kinesia.

GPi inhibits medullary reticular formation, which normally inhibits muscle tone. Pontine reticular formation self-generates its impulses and it normally increases muscle tone. A fine balance between the pontine and medullary reticulospinal tracts maintains normal muscle tone.

Pathologies of corpus striatum can be classified as ***hypokinetic, hypertonic*** conditions (e.g. Parkinson's disease) or ***hyperkinetic, hypotonic conditions*** (e.g., chorea, athetosis, and ballismus).

Circuitry of corpus striatum in Parkinson's disease (Figure 15.14)

In Parkinson disease, there is destruction of substantial nigra (Figure 15.14).

The thickened lines indicate fibres that are overacting; thinned out lines indicate the circuitry that are underacting in Parkinson's disease. The strong inhibitory impulse sent by GPi to medullary reticular foration causes an imbalance between the pontine and medullary reticulospinal tracts causing hypertonia. Similarly, inhibition of thalamo-cortical pathway results in hypokinesia.

The pin-rolling tremors, of 6–10 oscillations per second, seen at rest in Parkinson disease, is due to the resting discharge of dentate nucleus of cerebellum to the

ventrolateral nucleus of thalamus. Stereotactic ablation of ventrolateral nucleus of thalamus abolishes the tremors of Parkinson's disease.

Circuitry of corpus striatum in chorea or ballismus (Figure 15.15)

In the hyperkinetic, hypotonic disorders, the pathways for muscle tone and kinesia reverse when compared to Parkinson's disease. Chorea (or choreo-athetotic movements) is caused by destruction of D2 neurons of striatum. The condition is usually bilateral. Hyperkinesia, in chorea, affects proximal joints while that of athetosis involves distal joints. Both these conditions usually occur together (athetosis occurs alone in diffuse hypermyelinisation of striatum).

Hemorrhagic involvement of subthalamic nucleus causes violent, flinging movements (ballismus). Since, at a time, hemorrhage involves only one subthalamic nucleus, the condition is called hemiballismus. Hemiballismus occurs on the contralateral side of the affected subthalamus.

Wilson's Disease (Hepatolenticular Degeneration)

Wilson's disease is a rare, autosomal-recessive inherited disorder of copper metabolism resulting in accumulation of copper in liver. The pathology is degeneration of putamen and lenticular nucleus. Accumulation of copper in the eye is characterized by Kayser-Fleischer rings, which are whitish rings at the sclerocorneal junction or limbus.

Multiple Choice Questions

1. Which one of the following constitutes the basal nuclei of the cerebrum?
 A. Habenular nucleus
 B. Geniculate bodies
 C. Claustrum
 D. Subthalamus

2. The term "neostriatum" includes
 A. Caudate nucleus and putamen
 B. Globus pallidus
 C. Caudate nucleus and globus pallidus
 D. Amygdaloid nucleus

3. The head of the caudate nucleus becomes continuous with the
 A. Lentiform nucleus
 B. Amygdaloid body
 C. Claustrum
 D. Thalamus

4. The tail of the caudate nucleus ends in relation to
 A. Thalamus
 B. Cerebral fornix
 C. Amygdaloid body
 D. Claustrum

5. The body of caudate nucleus is related to which part of the lateral ventricle?
 A. Anterior horn
 B. Posterior horn
 C. Inferior horn
 D. Central part

6. A lesion of the basal nuclei can produce
 A. Hypotonia
 B. Intention tremor
 C. Muscular atrophy
 D. Aphasia

7. Parkinson's disease is due to a lesion of
 A. Amygdaloid body
 B. Lentiform nucleus
 C. Substantia nigra
 D. Dorsal nucleus of thalamus

8. Which of the following neurotransmitters is deficient in Parkinson's disease?
 A. GABA
 B. Serotonin
 C. Dopamine
 D. Acetylcholine

Answers

1. C **2.** A **3.** A **4.** C **5.** D **6.** A **7.** C **8.** C

Chapter 16

Limbic System

Specific Learning Objectives

At the end of learning, the student shall be able to:
- Enumerate the components of limbic system
- Describe the connections and functions of limbic system
- Correlate the relevant clinical anatomy

INTRODUCTION

The limbic system includes the limbic lobe and the structures connected to it. In 1878, Broca coined the term 'limbic lobe' formed by structures present on the medial and inferior surface of the cerebral hemispheres which forms a 'border' / 'ring' around the brain stem.

Limbic system consists of several cortical and sub-cortical structures, which form a ring-like structure around the upper end of brainstem.

The term ***limbic system*** has been applied in the past to certain regions of the brain that are believed to play an important role in the control of visceral activity. Many of these areas have been considered as having a predominantly olfactory function, but it is now realized that this is not so.

The olfactory system in man is not only concerned with smell but also activates other neural systems for emotional behaviour and hence included as a part of limbic system.

Functions of the Limbic System

Some of the functions attributed to limbic system are as follows:
- Integration of olfactory, visceral, and somatic impulses reaching the brain
- Control of activities necessary for survival of the animal, including the procuring of food and eating behaviour
- Control of activities necessary for survival of the species, including sexual behaviour
- Emotional behaviour
- Retention of recent memory

These can be interfered within lesions of the region.

Components of the Limbic System

The limbic system consists of ***cortical*** and ***subcortical*** structures. The cortical regions include limbic lobe and hippocampal formation, and subcortical structures include amygdaloid nuclear complex, septal nuclei, hypothalamus, anterior nucleus of thalamus, and olfactory areas (Figure 16.1).

The limbic lobe consists of cingulate gyrus, isthmus, parahippocampal gyrus, and uncus (Figure 16.2).

Hippocampal formation includes hippocampus, dentate gyrus, gyrus fasciolaris, indusium griseum, and medial and lateral longitudinal striae (Figure 16.3).

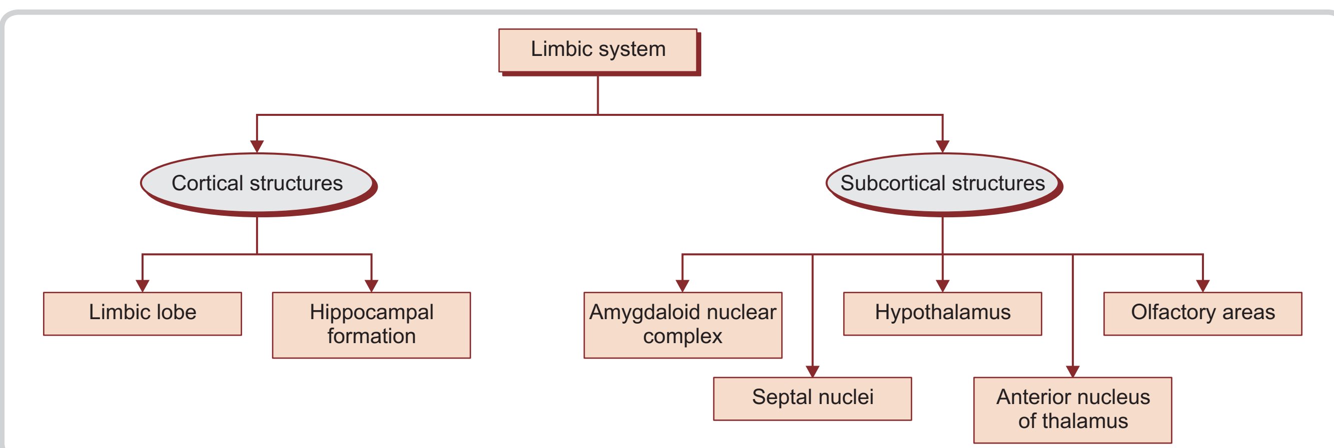

Figure 16.1: Components of Limbic System

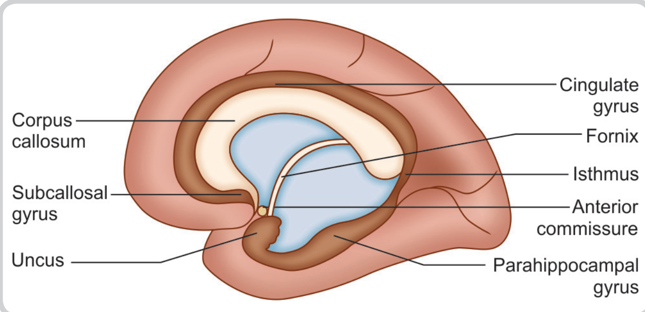

Figure 16.2: Midsagittal section of the brain showing the location of the limbic lobe. The limbic lobe consists of cingulate gyrus, isthmus, parahippocampal gyrus, and uncus

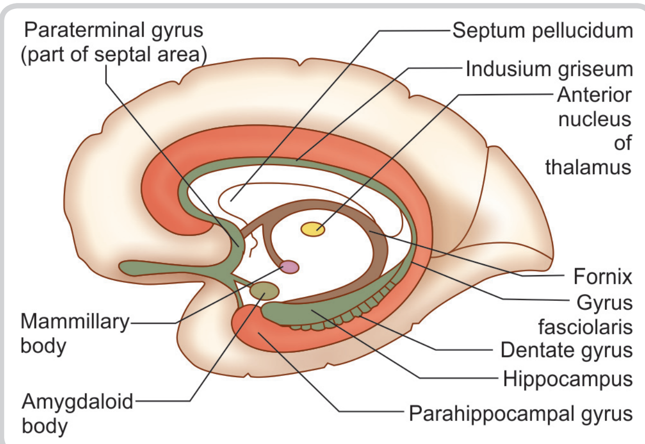

Figure 16.3: Midsagittal section of the brain showing the structures forming hippocampal formation (viz. hippocampus, dentate gyrus, gyrus fasciolaris, and indusium griesum)

AMYGDALOID NUCLEAR COMPLEX

This region is also called the amygdaloid body or amygdala. The complex lies in the temporal lobe of the cerebral hemisphere, close to the temporal pole. It lies deep to the uncus and is related to the anterior end of the inferior horn of the lateral ventricle.

Superiorly, the complex is related to the anterior part of the lentiform nucleus (Figure 16.4). Inferiorly, the complex is related to the gyrus semilunaris, the gyrus ambiens, and the uncinate gyrus i.e. anterior most part of parahippocampal gyrus (Figure 16.5). It fuses with the anterior end of the tail of the caudate nucleus. The lower end of the stria terminalis lies in relation to the amygdaloid complex.

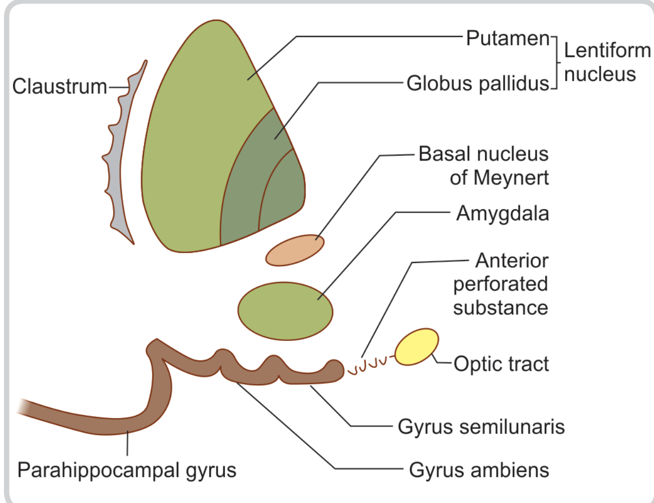

Figure 16.5: Some relations of the amygdala as seen in a coronal section

In the region between the amygdaloid complex and the lentiform nucleus, there is a region of substriatal grey matter, within which there is a collection of cholinergic neurons. These neurons form the ***basal nucleus of Meynert***. Some relations of the amygdaloid complex are shown in Figure 16.5.

Components

The amygdaloid complex is divided into a number of nuclei (Figure 16.6):

- ***Lateral***
- ***Medial***
- ***Basal***
- ***Central***
- ***Perilaminar***

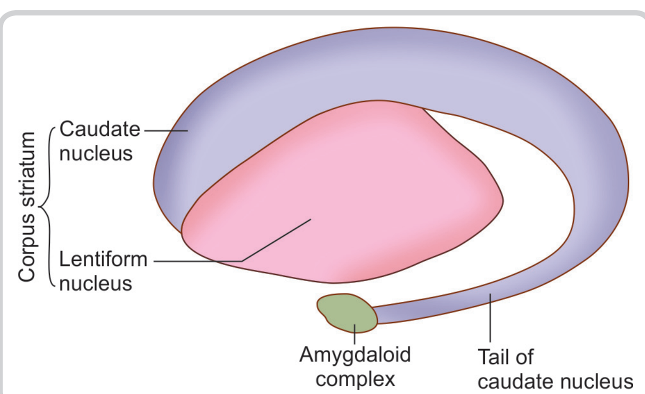

Figure 16.4: Scheme to show the structure and location of amygdaloid nuclear complex

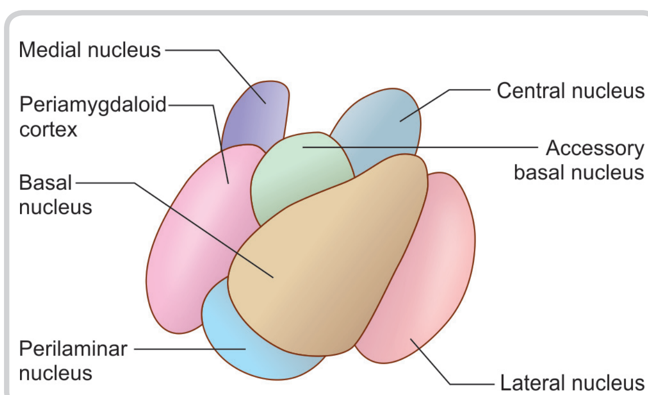

Figure 16.6: Subdivisions of the amygdaloid complex

The basal and lateral nuclei are collectively referred to as the ***basolateral nucleus***. Cells of the central and medial nuclei spread backwards along the stria terminalis and along with this extension, they are referred to as the ***extended amygdala***.

Connections

Efferent fibres from amygdala pass through two major routes:

- Stria terminalis—to septal nuclei, olfactory areas
- Ventral amygdalofugal route

Connections with the brainstem

- The amygdala receives fibres from and sends fibres to the reticular formation, particularly the parabranchial nucleus (Figure 16.7).
- Noradrenergic fibres from the locus coeruleus and serotoninergic fibres from the raphe nuclei reach the amygdala through the medial forebrain bundle. Dopaminergic fibres ascend from the ventral tegmental area of the midbrain.
- Some fibres from the amygdala reach the nucleus of the solitary tract and the dorsal nucleus of the vagus. The nucleus of the solitary tract projects back to the amygdala through the parabranchial nuclei. Through these connections, the amygdala receives gustatory and visceral information and can influence cardiovascular and respiratory functions.

Connections with the diencephalon

- The amygdala sends a major projection to various nuclei in the hypothalamus. Some fibres are also received from the hypothalamus.
- Fibres projecting to the thalamus end mainly in the medial dorsal nucleus. The impulses are relayed to the prefrontal cortex. Afferents are received from the ventral posterior nucleus (gustatory sensations) and from the medial geniculate body.

Connections with the corpus striatum

A prominent projection is sent to the striatum (caudate nucleus and putamen). Many fibres also reach the nucleus accumbens (which is a nucleus in the ventral striatum). Through the striatum, the amygdaloid complex indirectly influences the pallidum, which in turn projects to the medial dorsal nucleus of the thalamus. The amygdaloid complex sends many fibres to the basal nucleus of Meynert (lying in the region ventral to the corpus striatum). This projection is cholinergic. The nucleus projects back to the amygdala.

Cortical connections of amygdala

It is now known that in addition to its connections to olfactory areas, entorhinal area, and hippocampus, the

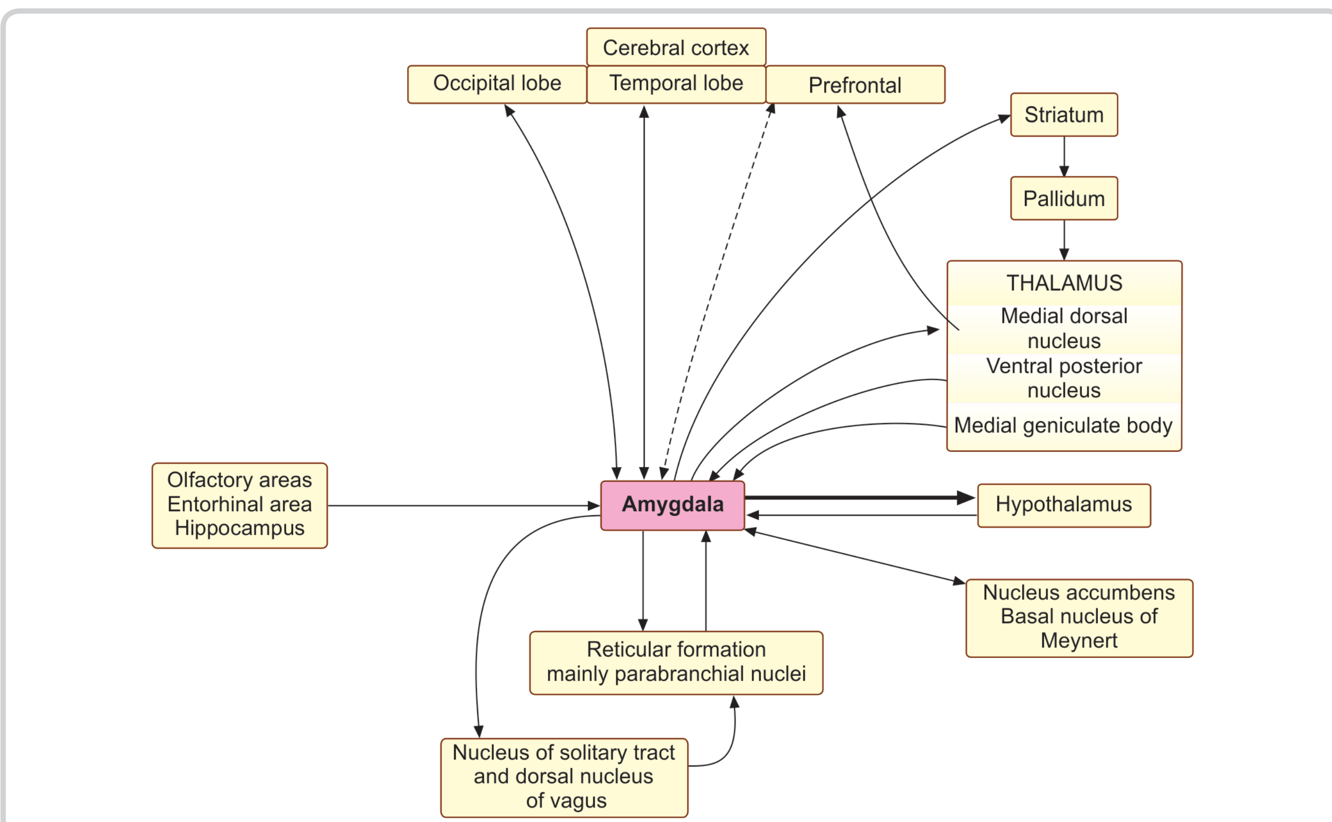

Figure 16.7: Scheme to show the main connections of the amygdala

amygdaloid complex has numerous connections with widespread areas of neocortex. The areas include the cingulate gyrus and parts of the frontal, temporal, and occipital lobes, including the visual and auditory areas.

Functions

- On the basis of all the connections described above and experimental studies, it appears probable that the amygdala plays an important role in the control of emotional behaviour.
- Since it receives olfactory inputs, it is believed that the amygdaloid body plays an important role in smell-mediated sexual behaviour.

> **Clinical Correlation**
>
> Lesions of the amygdaloid complex lead to the ***Kluver-Bucy syndrome***. The experimental animals appear to be unable to correctly evaluate its environment leading to gross and bizarre alterations in eating and sexual behaviour.

SEPTAL REGION

This term is used to designate certain masses of grey matter that lie immediately anterior to the lamina terminalis and the anterior commissure (Figure 16.8). The cerebral cortex of this region shows two small vertical sulci called the anterior and posterior ***parolfactory sulci.***

The region between the lamina terminalis and the posterior parolfactory sulcus is the ***paraterminal gyrus.*** The anterior part of this region, which adjoins the posterior parolfactory sulcus is called the ***prehippocampal rudiment.*** The region between the anterior and posterior parolfactory sulci is the ***subcallosal area*** (or ***parolfactory gyrus***). Most workers agree that the paraterminal gyrus (along with the prehippocampal rudiment) forms part of the septal region. Some include the subcallosal area as well. The cortex of this region is referred to as the ***septal area*** in distinction to the ***septal nuclei,*** which lie deep to the cortex.

Phylogenetically, the septal region is divided into a ***precommissural septum*** and a ***supracommissural septum***. The septal area is the precommissural septum. The supracommissural septum is represented by the septum pellucidum. The septal nuclei are divided into dorsal, ventral, medial, and caudal groups.

The septal area is continuous inferiorly with the medial olfactory stria. Superiorly, it is continuous with the indusium griseum (Figure 16.8). The septal nuclei are related inferiorly to the anterior perforated substance.

Connections

Septal nuclei predominantly receive afferents from

- Olfactory tract through medial olfactory stria
- Anygdala through stria terminals
- Hippocampus through fornix

Efferent corrections from septal nuclei are predominantly to habenular nuclei through stria medullaris thalami (stria habenularis).

HIPPOCAMPAL FORMATION

In the human embryo, the hippocampal formation develops in relation to the medial surface of each cerebral hemisphere close to the choroid fissure of the lateral ventricle. It is at first approximately, C-shaped in accordance with the outline of the body and inferior horn of the ventricle. The upper part of the formation is, however, separated from the ventricle, because of the development of the corpus callosum between the two. For the same reason, this part of the formation remains underdeveloped and is represented by a thin layer of grey matter, lining the upper surface of the corpus callosum. This layer is the ***indusium griseum.***

Within the indusium griseum are embedded two bundles of longitudinally running fibres called the ***medial*** and ***lateral longitudinal striae*** (on each side of the midline). Posteriorly, the indusium griseum is continuous with a thin layer of grey matter related to the inferior aspect of the splenium of the corpus callosum. This grey matter is the ***splenial gyrus*** or ***gyrus fasciolaris.*** The splenial gyrus runs forwards to become continuous with the ***dentate gyrus,*** present in relation to the inferior horn of the lateral ventricle.

In the region of the inferior horn of the lateral ventricle, the developing hippocampus is pushed into the cavity of the ventricle, because of the great development of the neighboring neocortex. The hippocampal formation is best developed in this region and forms the ***hippocampus***. This term includes the dentate gyrus.

Several subdivisions of the region are described. These are illustrated in Figure 16.9, which represents a coronal section through the inferior horn of the lateral ventricle. In this figure, note that the cavity of the inferior horn is closed, on the medial side, only by apposed layers of pia mater and ependyma. A fold of pia mater (tela choroidea) projects into the ventricle and encloses a bunch of capillaries that constitute the choroid plexus. This fissure through which the tela choroidea projects into the ventricle is the ***choroid fissure.*** The cerebral cortex that lies below the choroid fissure is S-shaped in cross-section. The upper and middle limbs of the 'S' are separated by the ***hippocampal fissure.*** The superior limb of the 'S' forms the hippocampus. The hippocampus consists of two parts. The part that forms the superior convex surface is called ***Ammon's horn*** or ***cornu ammonis.*** This is the hippocampus proper. The deeper part, which lies below and medial to Ammon's horn and forms the upper wall of the hippocampal fissure, is the ***dentate gyrus.*** The middle limb of the 'S' connects the cornu ammonis to the parahippocampal gyrus, which forms the lower limb of the 'S'. The middle limb is an area

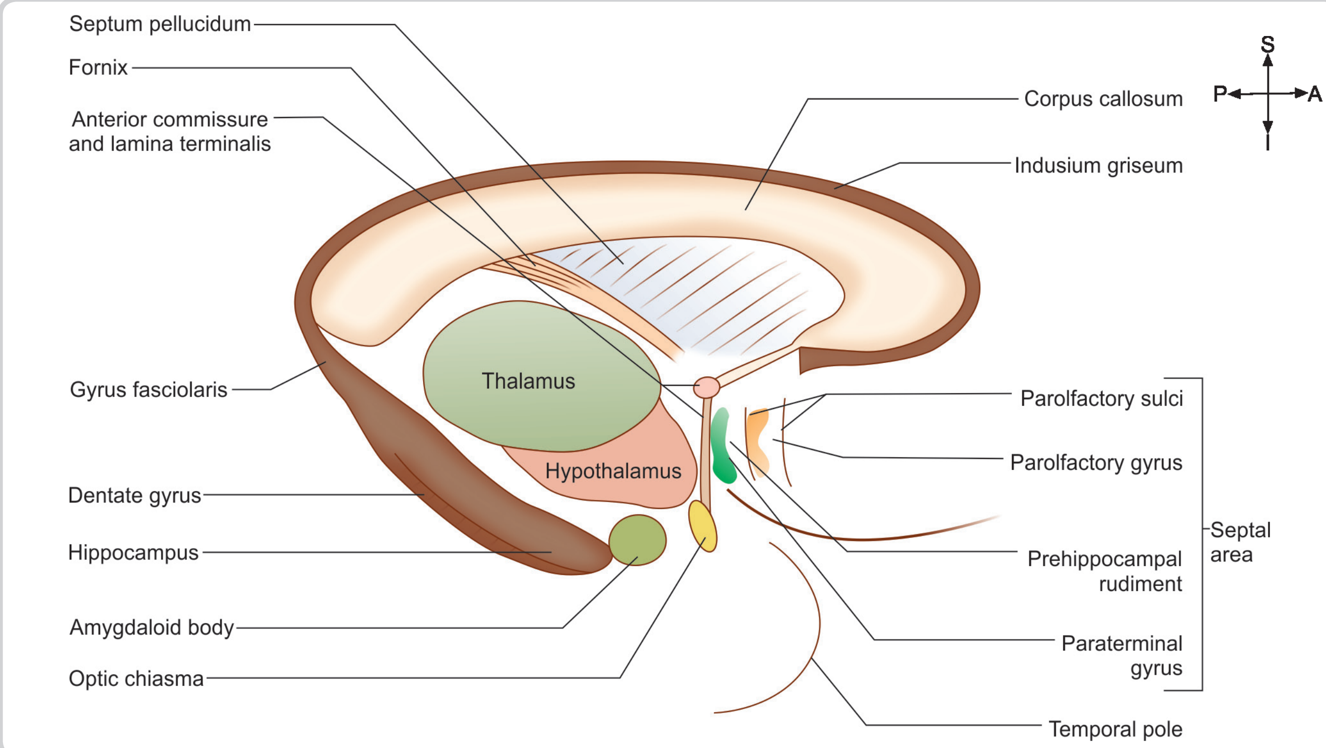

Figure 16.8: The hippocampal formation and related structures. Note the position of the parolfactory sulci and gyri

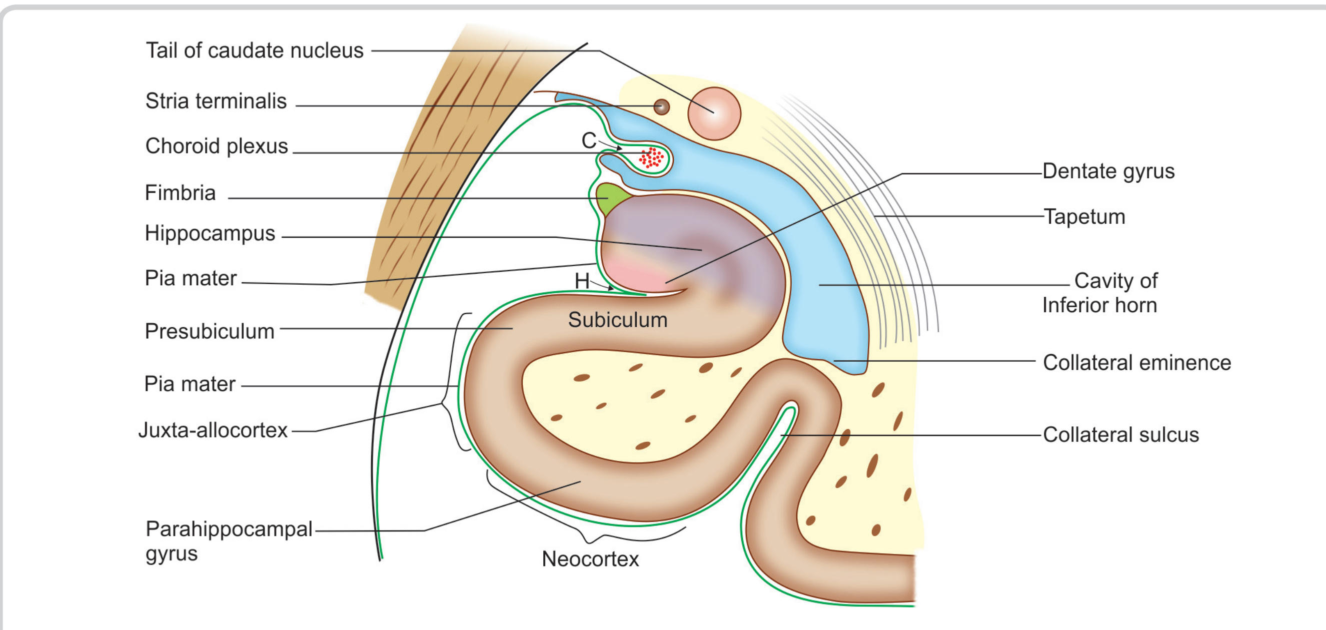

Figure 16.9: Coronal section through the cerebral hemisphere in the region of the inferior horn of the lateral ventricle to show the hippocampus and related structures. C=choroid fissure. H=hippocampal fissure

of transition between the parahippocampal gyrus and the cornu ammonis. It is called the ***subiculum*** (Figure 16.10).

The hippocampus forms a longitudinal projection that occupies the greater part of the floor of the inferior horn of the lateral ventricle. Its anterior end is expanded and notched and resembles a foot. It is, therefore, called the ***pes hippocampi.***

The ventricular surface of the hippocampus is covered by a layer of nerve fibres that constitute the ***alveus.*** The fibres of the alveus pass medially and collect to form a

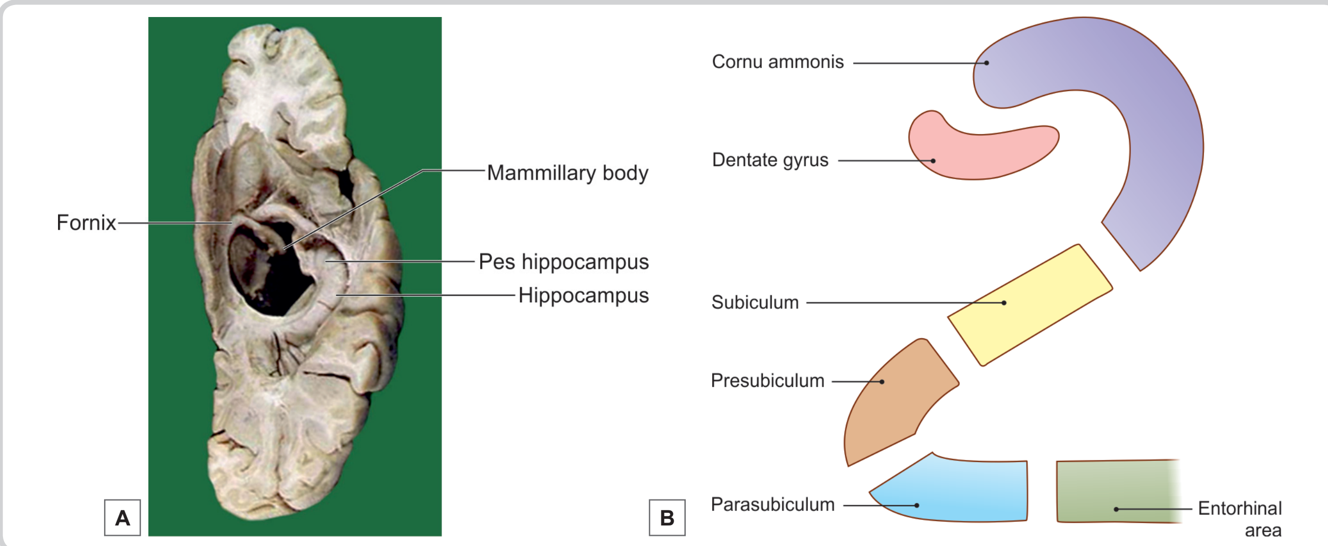

Figure 16.10: (**A**) Dissected brain specimen to show hippocampus (**B**) Schematic diagram to show the parts of hippocampus

bundle of fibres, the ***fimbria,*** that project above the medial part of the hippocampus (Figures 16.9 and 16.11).

The fimbria runs backwards along the medial side of the hippocampus to become continuous with the fornix.

The ***dentate gyrus*** is a longitudinal strip of grey matter. Laterally, it is fused with the cornu ammonis. Its medial margin is free and bears a series of notches that give it a dentate appearance; hence, the name dentate gyrus. When traced anteriorly, the dentate gyrus runs medially across the inferior surface of the uncus. This part is called the ***tail of the dentate gyrus***. As stated above, the posterior end of the dentate gyrus is continuous with the splenial gyrus (gyrus fasciolaris) (Figure 16.8). Because of its close relations to the dentate gyrus, the uncus is sometimes regarded as part of the hippocampal formation.

Note: The structure of the hippocampus is different from that of the rest of the cerebral cortex. While most of the cerebral cortex is six-layered, the hippocampal cortex is made up of three layers only (Figure 16.11). These are as follows:

- Superficial molecular layer
- Middle pyramidal cell layer
- Deep polymorphic cell layer

The subiculum is a transitional zone in which a gradual reduction in the number of layers takes place.

Connections of the Hippocampus

Afferents: Hippocampus receives fibres mainly from entorhinal area (area 28). (Olfactory cortex), amygdala, opposite hippocampus, cingulate gyrus.

Efferents: The fornix is the main efferent tract of the hippocampus.

The fibres leaving the hippocampus pass:

- To the opposite hippocampus through the ***commissure of fornix/hippocampal commisure***
- To the septal and anterior hypothalamic regions
- To the mammillary body, which sends impulses to cingulate gyrus through anterior nucleus of thalamus, through Papez circuit.

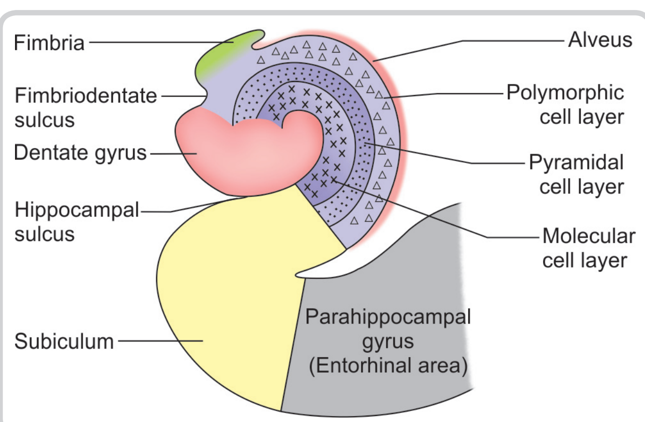

Figure 16.11: Coronal section of the hippocampus

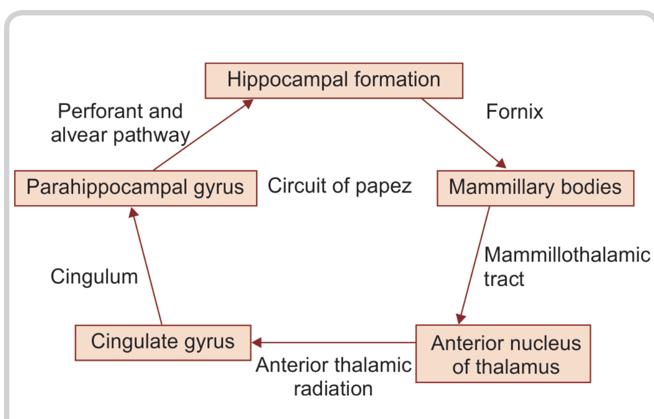

Figure 16.12: Papez circuit

Papez Circuit (Hippocampal Circuit)

It is a circular pathway that interconnects certain important structures in limbic system (Figure 16.12). Papez in 1937 described a circuit, begining and ending in hippocampus linking hippocampal formation with cingulated gyrus, mammillary bodies and hypothamus. It contains the following stations: the hippocampus projecting via the fornix to mammillary nucleus, the mammillary nucleus projecting via the mammillothalamic tract to the anterior nucleus of thalamus, anterior nucleus of thalamus projecting to the cingulate gyrus, and the cingulate gyrus projecting via the cingulum back to the hippocampus.

Neuroscientist Paul D. MacLean proposed a modified version of Papez circuit in 1952, stating that it is not only hippocampus but also amydala and septal area are involved and hence the circuit is related to memory and emotion. MacLean further stated that involvement of visceral brain in the limbic system accounted functions of limbic system for behaviour, motivation, and olfaction.

Mammillothalamic Tract

Mammillothalamic tract (also called ***bundle of Vicq d' Azyr***) is the bundle of fibres, which carries impulses from mammillary body to the anterior nucleus of thalamus. It also includes some thalamo-mammillary fibres. The efferents from anterior nucleus thalamus are projected mainly to areas 23 and 24 of the cingulate gyrus. Some fibres also reach the tegmental nuclei of the midbrain through mammillotegmental tract.

FIBRE BUNDLES OF LIMBIC REGION

Stria Terminalis

This bundle of fibres is closely related to the inferior horn and central part of the lateral ventricle (Figure 16.9). It begins in the amygdaloid complex and runs backwards in the roof of the inferior horn. It then winds upwards and forwards to lie in the floor of the central part of the ventricle. Finally, it terminates near the interventricular foramen and anterior commissure by dividing into various smaller bundles. Throughout its course, it is closely related to the medial side of the caudate nucleus (Figure 12.2). In the inferior horn, it is related to the tail of this nucleus. In the central part of the ventricle, it lies medial to the body of the caudate nucleus. Here, the thalamus is medial to it. A group of neurons located just behind the anterior commissure is sometimes described as the nucleus of the stria terminalis.

The stria terminalis contains the following fibres (as traditionally described):

- Fibres from the amygdaloid complex to the septal region, the hypothalamus, the anterior perforated substance, the piriform lobe, and the nucleus of the stria terminalis.
- Fibres from the amygdaloid nucleus to the habenular nuclei. These fibres leave the stria at its anterior end and reach the habenular nuclei through the stria medullaris thalami.
- Some fibres from the amygdaloid complex run forwards in the stria, cross to the opposite side in the anterior commissure, and then run backwards in the stria of the opposite side to reach the opposite amygdaloid complex.
- Fibres from the septal areas and adjoining regions possibly run backwards in the stria to reach the amygdaloid complex.

Anterior Commissure

The anterior commissure is situated in the anterior wall of the third ventricle at the upper end of the lamina terminalis (Figure 16.8).

When traced laterally, it divides into anterior and posterior bundles. The posterior bundle passes below the lentiform nucleus. Fibres passing through the commissure interconnect the regions of the two cerebral hemispheres concerned with the olfactory pathway. These include the olfactory bulb, the anterior olfactory nucleus, the prepiriform cortex, the entorhinal area, the anterior perforated substance, the amygdaloid complex, and related structures. Other fibres interconnect the parahippocampal gyri and other parts of the two temporal lobes. Some fibres interconnect the frontal lobes of the two sides, especially the orbital gyri.

Fornix

The fornix is a prominent bundle of fibres seen on the medial aspect of the cerebral hemisphere. It is predominantly made up of fibres arising in the hippocampus. The ***body*** of the fornix is suspended from the corpus callosum by the septum pellucidum (Figures 12.2 and 13.8) and comes into close relations with the tela choroidea in the roof of the third ventricle. When traced posteriorly, the body of the fornix divides into two parts called ***crura.*** Each crus of the fornix becomes continuous with the fimbria of the corresponding side. The two crura are interconnected by fibres passing from each other. These crossing fibres constitute the ***hippocampal commissure*** or ***commissure of the fornix.*** The anterior end of the body of the fornix also divides into right and left halves called the ***columns*** of the fornix. Each column turns downwards just in front of the interventricular foramen and passes through the hypothalamus to reach the mammillary body (Figure 16.13).

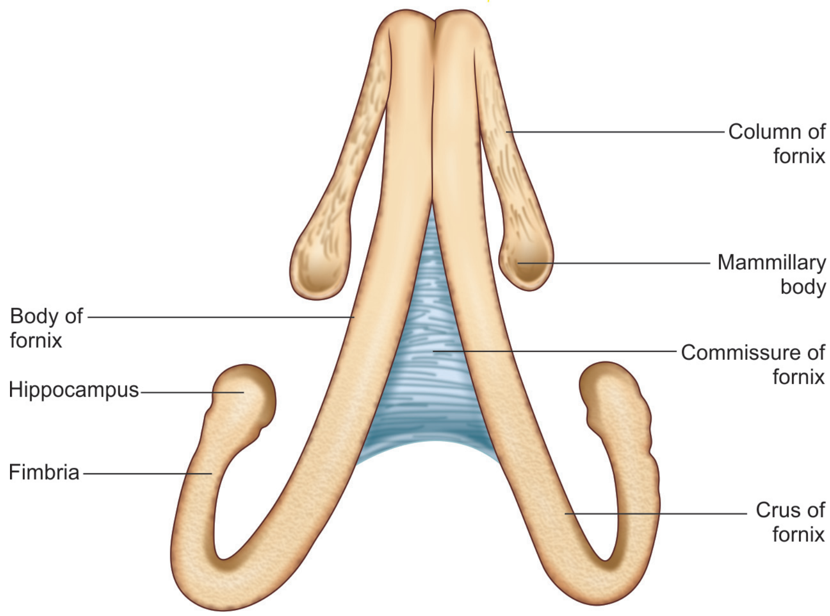

Fig. 16.13: Dorsal view of hippocampus and fornix to show the commissure of fornix

Most of the fibres of the fornix lie behind the anterior commissure and are, therefore, referred to as the ***postcommissural fornix.*** In contrast, some fibres of the fornix that descend in front of the anterior commissure constitute the ***precommissural fornix.*** Some of the fibres of the fornix pass above the splenium of the corpus callosum to reach structures above the latter. These fibres constitute the ***dorsal fornix.***

The fibres contained in the fornix are as follows:

- Fibres interconnecting the hippocampi of the two sides through the hippocampal commissure.
- Fibres from the hippocampus that pass through the postcommissural fornix to reach the mammillary body. These are then relayed to the anterior nucleus of the thalamus. Some fibres of the fornix end directly in this nucleus and some in the hypothalamus.
- Fibres from the hippocampus that pass through the precommissural fornix reach the septal region. Some of these fibres turn backwards to enter the stria medullaris thalami and reach the habenular nuclei.
- Fibres entering the dorsal fornix reach the splenial gyrus and the gyrus cinguli.

Clinical Correlation

Disorders of Memory and Behaviour

Some neurological disorders are associated with impairment of memory (***amnesia***-loss of memory). It is now known that discrete areas of the brain are involved in memory and different areas influence different modalities of memory. The best known 'system' damage of which leads to defects of memory, consists of the hippocampus (including the subiculum), the fimbria and fornix, the mammillary bodies, the mammillothalamic tract, the anterior nuclei of the thalamus, and the gyrus cinguli (and the fibres of the cingulum). It has been shown that damage anywhere along this pathway results in loss of memory of events, leaving general knowledge of the person intact. Bilateral transection of the fornix can lead to acute amnesic syndrome, in which an individual is unable to process his/her short-term memory into long-term memory.

Kluver Bucy syndrome results due to bilateral temporal lobe lesion involving amygdala, hippocampal formation and adjacent structures. The amygdala is probably responsible for evaluating the signifcance of environmental events, for example in recognising what objects are edible, or in recognising attributes of the opposite sex. This results in marked changes in ingestive behaviour, the animal ingests material (like fecal matter), not normally eaten. Abnormalities in sexual behaviour are also seen probably, because of the failure to distinguish between male and female animals.

The ***nucleus accumbens***, located in the ventral striatum is a part of the mesolimbic dopamine system. It has acquired importance following the recognition that this nucleus is concerned with simulating pleasure giving effects of addictive drugs (such as nicotine and alcohol).

Alzheimer's disease is a degenerative disorder of the brain affecting the limbic system. It is associated with loss of memory, initially short-term and later long-term memory. Cognitive deficit is due to reduced cholinergic inputs.

contd...

Multiple Choice Questions

1. The fibres of the column of the fornix end in
   A. Mammillary body
   B. Caudate nucleus
   C. Hypothalamus
   D. Collateral eminence
2. The following structures are included in the "Papez circuit" EXCEPT
   A. Fornix
   B. Mammillary body
   C. Medial nucleus of thalamus
   D. Hippocampus
3. The hippocampal formation consists of
   A. Dentate gyrus
   B. Indusium griseum
   C. Gyrus fasciolaris
   D. All of the above
4. The fibres of the fornix arise from
   A. Mammillary body
   B. Hippocampus
   C. Amygdaloid body
   D. Collateral eminence
5. The layer of white fibres covering the ventricular surface of the hippocampus is known as
   A. Pes hippocampi
   B. Alveus
   C. Fimbria
   D. Stria terminalis
6. Cingulate gyrus is a part of
   A. Hippocampal formation
   B. Limbic Lobe
   C. Subcallosal area
   D. Olfactory Area

Answers

1. A **2.** C **3.** D **4.** B **5.** B **6.** B

Chapter 17

Ventricles of the Brain and CSF Circulation

Specific Learning Objectives

At the end of learning, the student shall be able to:
- Describe the features of lateral, third and fourth ventricles
- Describe the circulation of cerebrospinal fluid (CSF) and the blood-CSF barrier
- Describe the relevant clinical anatomy

INTRODUCTION

The interior of the brain contains a series of cavities (Figure 17.1). The cerebrum contains a median cavity, the ***third ventricle,*** and two ***lateral ventricles***, one in each hemisphere. Each lateral ventricle opens into the third ventricle through an ***interventricular foramen***.

The third ventricle is continuous caudally with the ***cerebral aqueduct,*** which traverses the midbrain and opens into the fourth ventricle.

The ***fourth ventricle*** is situated dorsal to the pons and medulla and ventral to the cerebellum. It communicates inferiorly, with the ***central canal,*** which traverses the lower part of the medulla and the spinal cord. The entire ventricular system is lined by an epithelial layer called the ***ependyma.***

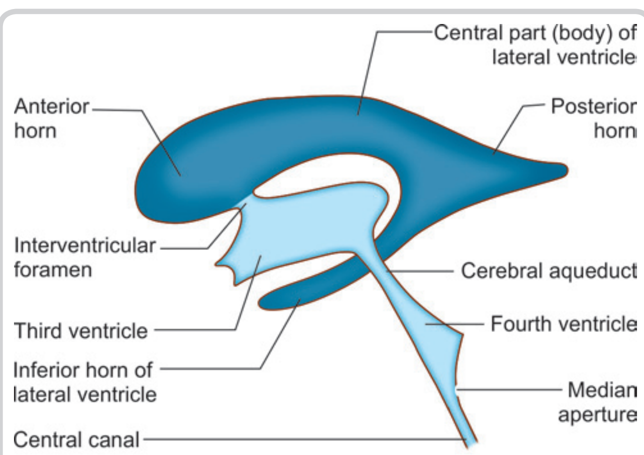

Figure 17.1: Ventricular system of the brain seen from the lateral side

LATERAL VENTRICLES

The lateral ventricles are two cavities, one situated within the telencephalic part of each cerebral hemisphere. Each ventricle is a C-shaped cavity, consisting of ***four parts***, i.e. a ***central part (body)***, in the parietal lobe, from which three extensions are given off in the frontal, occipital and temporal lobes, called the ***anterior***, ***posterior*** and ***inferior horns*** (Figure 17.2). The ***atrium*** **(*trigone*)** of the lateral ventricle is the site of confluence of the body, posterior and inferior horns. It is the most dilated part of the lateral ventricle.

Central Part

The central part of the lateral ventricle is elongated antero-posteriorly. Anteriorly, it becomes continuous with the anterior horn at the level of the interventricular foramen. Posteriorly, the central part reaches the splenium of the corpus callosum.

The central part is triangular in cross section (Figure 17.3). It has a roof, a floor, and a medial wall. The roof and floor meet on the lateral side. The ***roof*** is formed by the trunk of the corpus callosum. The ***medial wall*** is formed by the septum pellucidum and by the body of the fornix. It is common to the two lateral ventricles. The ***floor*** is formed mainly by the superior surface of the thalamus, medially and by the caudate nucleus, laterally. Between these two structures, there are the stria terminalis, laterally and the thalamostriate vein, medially. From

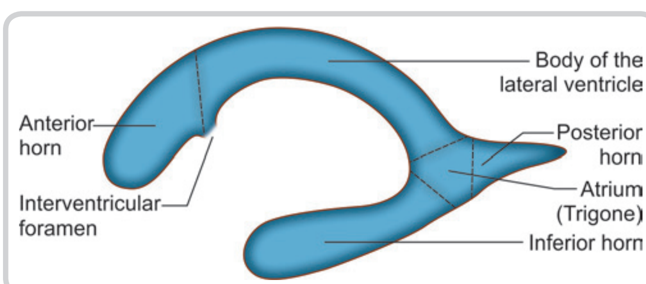

Figure 17.2: Parts of the lateral ventricle

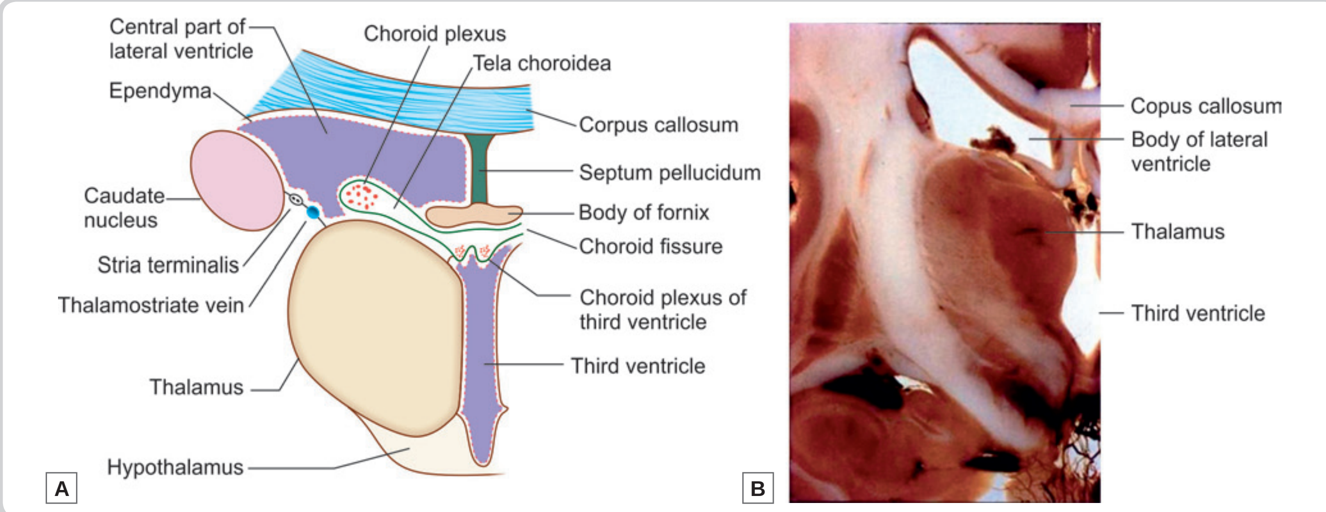

Figure 17.3: (**A**) Boundaries of the central part of the lateral ventricle and of the third ventricle (Note the relationship of the tela choroidea and the choroid plexuses to these ventricles) (**B**) Plastinated specimen of the brain, coronal section, showing the body of lateral ventricle

Figure 17.3, it will be seen that there is a space between the fornix and the upper surface of the thalamus. This is the ***choroid fissure.***

A fold of pia mater, the ***tela choroidea***, invaginates into the ventricle through the fissure and covers part of the thalamus. The tela choroidea is common to the two lateral ventricles and third ventricle. Within each lateral edge of the tela choroidea, there are plexuses of blood vessels that constitute the ***choroid plexus*** (***vascularized tela choroidea***) (Figure 17.3A). The tela choroidea and other structures forming the walls of the ventricle are lined by ependyma.

Anterior Horn

The anterior horn of the lateral ventricle lies anterior to its central part; the two being separated by an imaginary vertical line drawn at the level of the interventricular foramen (Figure 17.1). This horn is triangular in section. It has a roof, a floor, and a medial wall (Figure 17.4A). It is closed anteriorly by the genu and rostrum of the corpus callosum.

The ***roof*** is formed by the most anterior part of the trunk of the corpus callosum. The floor is formed mainly by the head of the caudate nucleus. A small part of the floor, near the middle line, is formed by the upper surface of the rostrum of the corpus callosum.

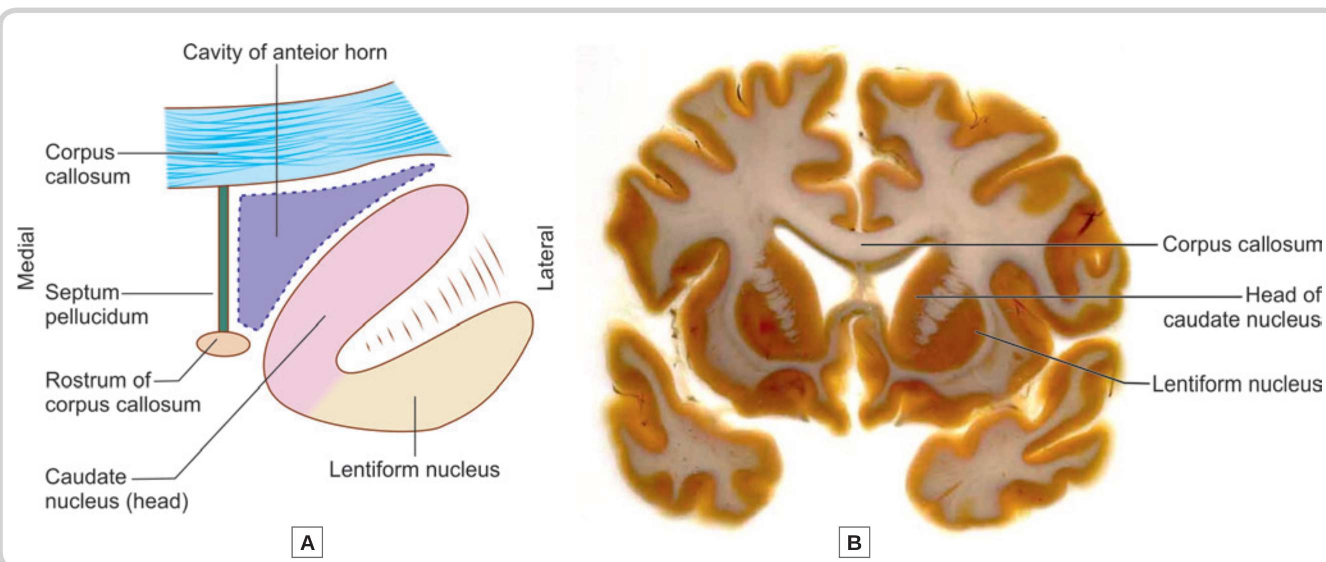

Figure 17.4: (**A**) Boundaries of the anterior horn of the lateral ventricle. (**B**) Plastinated specimen of the brain showing anterior horns of lateral ventricles in a coronal section

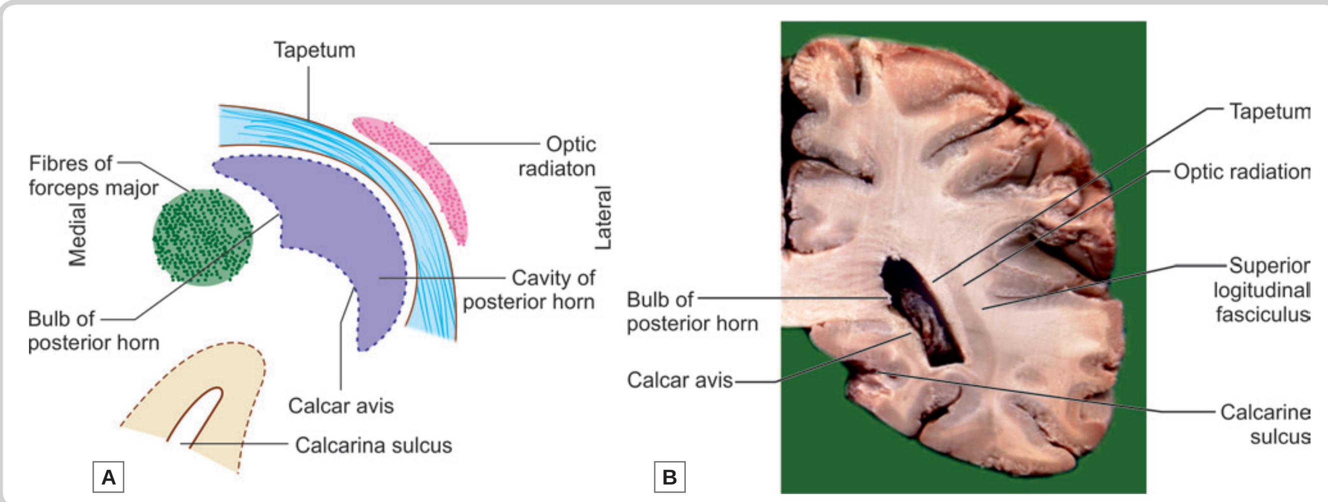

Figure 17.5: (**A**) Coronal section passing through posterior horn of the lateral ventricle. (**B**) Photograph of a coronal section of the brain through left posterior horn viewed from the anterior aspect

The ***medial wall*** (common to the two sides) is formed by the septum pellucidum. It may be noted that the tela choroidea and the choroid plexus ***do not*** extend into the anterior horn.

Posterior Horn

The posterior horn of the lateral ventricle extends backwards into the occipital lobe. It has a roof, a lateral wall, and a medial wall (Figure 17.5).

The ***roof*** and ***lateral wall*** are formed by the tapetum (a sheet of fibres from the splenium of the corpus callosum). The ***medial wall*** shows two elevations. The uppermost of these is the ***bulb of the posterior horn***, which is produced by fibres of the forceps major, as they run backwards from the splenium of the corpus callosum. The lower elevation is called the ***calcar avis***. It represents white matter '***pushed in***' by formation of the calcarine sulcus.

Inferior Horn

The inferior horn of the lateral ventricle begins at the posterior end of the central part. It runs downwards and forwards into the temporal lobe, its anterior end reaching close to the uncus.

In considering the structures to be seen in the walls of the inferior horn, it is useful to note that the anterior horn, the central part, and the inferior horn form one continuous C-shaped cavity. From Figure 17.1, it will be obvious that the floor of the central part of the ventricle is continuous with the roof of the inferior horn. It is also useful to recall that the body of the fornix divides posteriorly into two crura, which become continuous with the fimbria and hippocampus.

In the central part of the ventricle, the choroid fissure lies below the fornix. When traced into the inferior horn, the fissure lies ***above*** the fimbria and hippocampus. The choroid plexus extends into the inferior horn through the choroid fissure.

In cross section, the inferior horn is seen to have a narrow cavity (Figure 17.6). The cavity is bounded above and laterally by the ***roof*** and below and medially by the ***floor.*** Because of this orientation, the lateral part of the

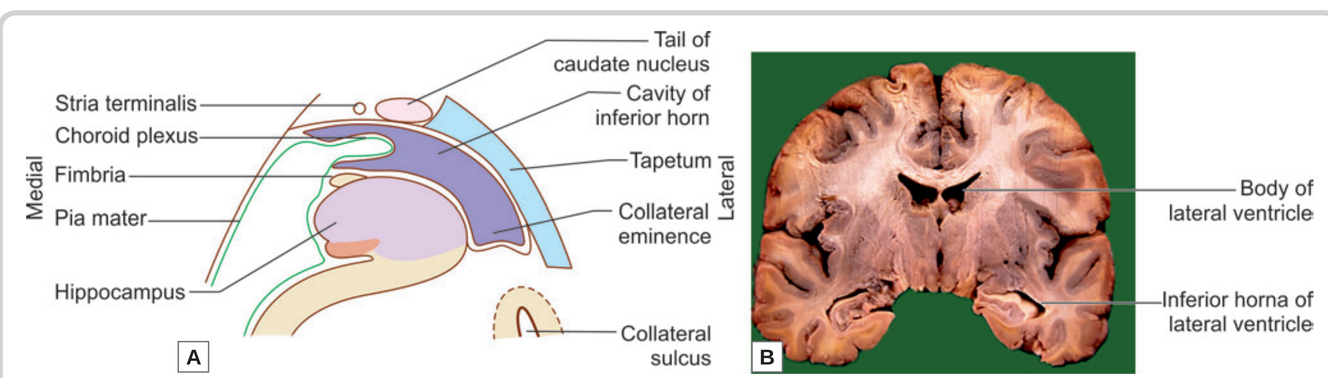

Figure 17.6: (**A**) Boundaries of the inferior horn of the lateral ventricle (coronal section). (**B**) Photograph of the coronal section of brain showing the body and inferior horn of lateral ventricle

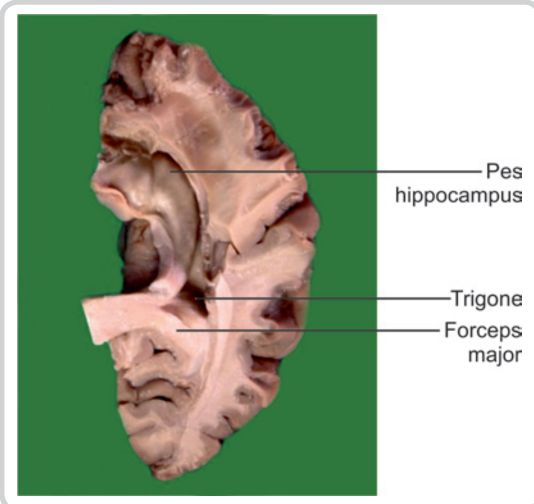

Figure 17.7: Photograph of the right inferior horn of the lateral ventricle viewed from above in a dissected brain

roof is sometimes called the ***lateral wall*** and the medial part of the floor, the ***medial wall.***

The lateral part of the roof is formed by fibres of the tapetum. The medial part of the roof is formed by the tail of the caudate nucleus, laterally and the stria terminalis, medially. These structures are continued into the roof of the inferior horn from the floor of the central part. Anteriorly, the tail of the caudate nucleus and the stria terminalis end in relation to the amygdaloid complex, which lies in the most anterior part of the roof.

The floor of the inferior horn is formed mainly by the hippocampus (Figures 17.6 and 17.7). The fibres of hippocampus form a thin sheet of white matter called ***alveus*** that covers its ventricular surface. The fibres of alveus converge medially to form a ridge called ***fimbria*** (Figure 16.3). In the lateral part of the floor, there is an elevation, the ***collateral eminence***, produced by inward bulging of the white matter by the collateral sulcus.

THIRD VENTRICLE

The third ventricle is the cavity of the diencephalon. It is a median cavity situated between the right and left thalami (Figure 17.3). It communicates on either side with the lateral ventricle through the interventricular foramen (Figures 17.1 and 17.8). Posteriorly, it continues into the cerebral aqueduct, which connects it to the fourth ventricle. The ventricle has two lateral walls, floor, and roof.

Each ***lateral wall*** is marked by the ***hypothalamic sulcus*** (Figure 17.8), which follows a curved course from the interventricular foramen to the aqueduct. Above the sulcus, the wall is formed by the medial surface of the thalamus. The two thalami are usually connected by a band of grey matter called the ***interthalamic connexus,*** which passes through the ventricle. The lateral wall, below the hypothalamic sulcus, is formed by the medial surface of the hypothalamus. A small part of the lateral wall, above and behind the thalamus, is formed by the epithalamus.

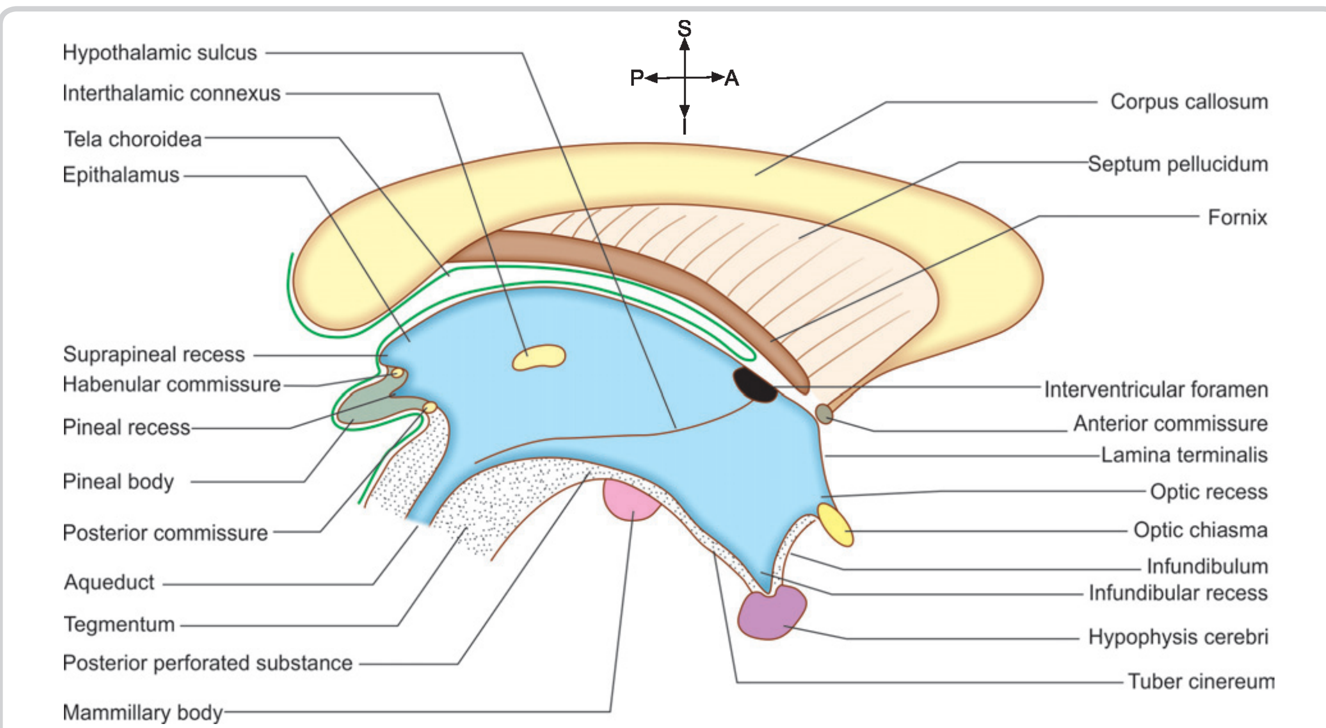

Figure 17.8: Boundaries and recesses of the third ventricle.
Note the mode of formation of the tela choroidea that lies in the roof of the ventricle

The interventricular foramen is seen on the lateral wall, just behind the column of the fornix.

The ***anterior wall*** of the third ventricle is formed mainly by the lamina terminalis. Its upper part is formed by the anterior commissure and columns of the fornix, as they diverge from each other.

The ***posterior wall*** is formed by the pineal body and posterior commissure and habenular commissure.

The ***floor*** is formed by the optic chiasma, tuber cinereum, infundibulum, mammillary bodies, posterior perforated substance, and the tegmentum of the midbrain.

The ***roof*** of the ventricle is formed by the ependyma that stretches across the two thalami (Figure 17.3). Above the ependyma, there is the tela choroidea. Within the tela choroidea, there are two plexuses of blood vessels (one on either side of the middle line), which bulge downwards into the cavity of the third ventricle. These are the choroid plexuses of the third ventricle (Figure 17.9).

The cavity of the third ventricle shows a number of prolongations or recesses (Figure 17.8). The ***infundibular recess*** extends into the infundibulum. The ***optic recess*** lies just above the optic chiasma. The ***pineal recess*** lies between the superior and inferior laminae of the stalk of the pineal body. The ***suprapineal recess*** lies above the pineal body in relation to the epithalamus.

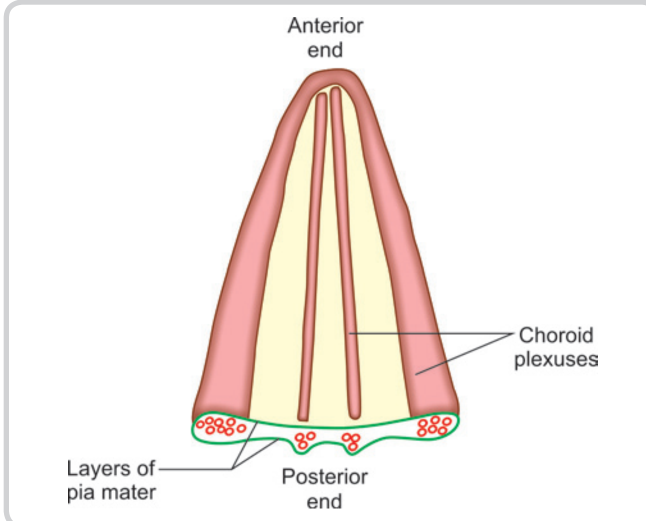

Figure 17.9: Schematic diagram of the tela choroidea removed and viewed from above

Tela Choroidea of the Third and Lateral Ventricles

The tela choroidea is a double-layered fold of pia mater that occupies the interval between the splenium of the corpus callosum and fornix above and the two thalami below. It is triangular in shape (Figure 17.9). Its posterior end is broad and lies in the gap between the splenium, above and the posterior part of the roof of the third ventricle, below (Figure 17.8). This gap is called the ***transverse fissure***. The anterior end (representing the apex of the triangle) lies near the right and left interventricular foramina. The median part of the tela choroidea lies on the roof of the third ventricle. Its right and left lateral edges project into the central parts of the corresponding lateral ventricles (Figure 17.3). When traced posteriorly, the two layers of pia mater forming the tela choroidea separate. The upper layer curves upwards over the posterior aspect of the splenium. The lower layer turns downwards over the pineal body and tectum (Figure 17.8).

Choroid Plexuses

The choroid plexuses are highly vascular structures that are responsible for the formation of CSF. The surface of each plexus is lined by a membrane formed by fusion of the ventricular ependyma with the pia mater of the tela choroidea. Deep to this membrane, there is a plexus of blood vessels. Microscopic examination shows that the surface of the choroid plexus has numerous villous processes. Each process contains a plexus of capillaries that are connected to afferent and efferent vessels. Because of the presence of these processes, the surface area of the choroid plexuses is considerable. It is further increased by the presence of microvilli (seen with the electron microscope) present on the ependymal cells.

Four choroid plexuses are to be seen in relation to the tela choroidea of the third and lateral ventricles (Figure 17.9). Two of these (one right and one left) lie along the corresponding lateral margins and project into the central part of the corresponding lateral ventricle. Two other plexuses run parallel to each other, one on either side of the midline. These are the choroid plexuses of the third ventricle. At each posterolateral angle of the tela choroidea, the choroid plexus of the lateral ventricle continues into the inferior horn. The pial covering for this part of the plexus is provided by simple invagination of the pia mater, covering the medial aspect of the hemisphere, through the inferior part of the choroid fissure.

The choroid plexus of the third ventricle is formed by the medical and lateral posterior choroidal branches of posterior cerebral artery. The same extends into the central part of each lateral ventricle through the choroid fissure. The choroid plexus of inferior horn of lateral ventricle is formed by the branches of anterior choroid artery. In the trigone, the choroid plexus is formed by the anastomoses of anterior and posterior choroidal arteries.

FOURTH VENTRICLE

For a proper understanding of the anatomy of the fourth ventricle, it is necessary that some features of the gross anatomy of the cerebellum and of related structures be clearly understood. Figure 17.10 will show that the

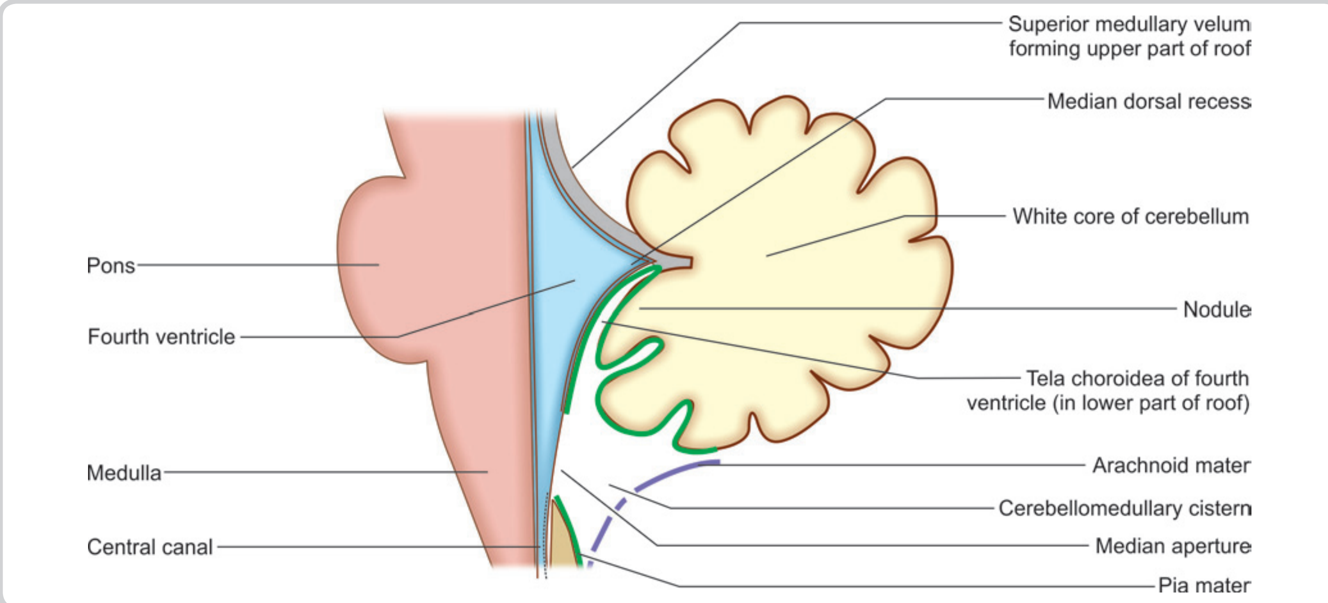

Figure 17.10: Midsagittal section passing through the fourth ventricle and related structures. The upper part of the ventricle is related to the ***superior (or anterior) medullary velum***. When traced inferiorly (and posteriorly), the velum merges into the white matter of the cerebellum. The lower part of the ventricle is related to the nodule. If the tonsil is lifted away, it will be seen that the nodule is continuous laterally with a membrane called the ***inferior (or posterior) medullary velum***

cerebellum is intimately related to the ventricle. The upper part of the ventricle is related to the ***superior (or anterior) medullary velum.*** When traced inferiorly (and posteriorly), the velum merges into the white matter of the cerebellum. The lower part of the ventricle is related to the nodule (Figure 17.8). It will be recalled that the nodule forms the anterior-most part of the inferior vermis. Immediately lateral to the nodule, there is the tonsil of the cerebellum. If the tonsil is lifted away, the nodule is seen continuous laterally with a membrane called the ***inferior (or posterior) medullary velum*** (Figure 17.11). Posteriorly, the inferior velum merges into the white matter of the cerebellum. The inferior medullary velum has a thickened free edge, which connects the nodule to the flocculus. This edge is the peduncle of the flocculus. In the intact brain, this peduncle is very near the posterior surface of the medulla and is separated from the inferior cerebellar peduncle only by a narrow interval.

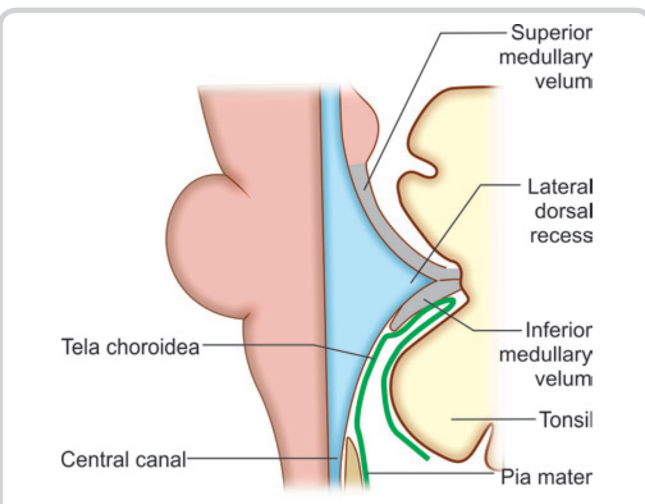

Figure 17.11: Parasagittal section passing through the fourth ventricle lateral to the nodule to show the relationship of the inferior medullary velum to the roof of the ventricle. Note that the lateral dorsal recess lies just superior to the velum

The fourth ventricle is a space situated dorsal to the pons and to the upper part of the medulla and ventral to the cerebellum.

For descriptive purposes, the ventricle may be considered as having a cavity, a floor, a roof, and lateral walls.

Cavity

The cavity of the ventricle is continuous inferiorly with the central canal and superiorly with the cerebral aqueduct. It communicates with the subarachnoid space through three apertures, one median and two lateral (Figures 17.10 and 17.14A). A number of extensions from the main cavity are described in Figure 17.12. The largest of these are two ***lateral recesses,*** one on either side. Each lateral recess passes laterally in the interval between the inferior cerebellar peduncle, ventrally and the peduncle of the flocculus, dorsally (Figure 17.14A). The lateral extremity of the recess reaches the flocculus. At this extremity, the recess opens into the subarachnoid space as the ***lateral aperture.*** Another recess present in the middle line is called the ***median dorsal recess.*** It extends into the white

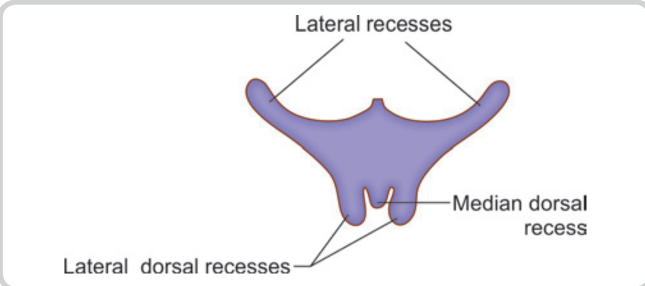

Figure 17.12: Scheme to show the various recesses of the cavity of the fourth ventricle

core of the cerebellum and lies just cranial to the nodule (Figures 17.10 and 17.12). Immediately lateral to the nodule, another recess projects dorsally, on either side, above the inferior medullary velum. These are the ***lateral dorsal recesses*** (Figures 17.11 and 17.12).

Openings in the Fourth Ventricle

The fourth ventricle communicates below (at its inferior angle) with the central part of medulla oblongata. It has three openings in the roof—one median and two lateral, through which it communicates with the subarachnoid space. The median opening (foramen of Magendie) is a large opening, in the lower part of the roof. Through this midline opening, it communicates with the cerebellomedullary cistern. Two lateral openings (foramina of Luschka), one on each side, lie in the lateral angle of the ventricle between the inferior cerebellar peduncle and flocculus. Through this opening, the CSF escapes into the subarachnoid space. The choroid plexus of the fourth ventricle also protrudes through this opening.

Floor

Because of its shape, the floor of the fourth ventricle is often called the ***rhomboid fossa*** (Figure 17.13). It is divisible into an upper triangular part formed by the posterior surface of the pons, a lower triangular part formed by the upper part of the posterior surface of the medulla, and an intermediate part at the junction of the medulla and pons. The intermediate part is prolonged laterally over the inferior cerebellar peduncle as the floor of the lateral recess. Its surface is marked by the presence of delicate bundles of transversely running fibres. These bundles are the ***striae medullares.***

The entire floor is divided into right and left halves by a ***median sulcus.*** Next to the middle line, there is a longitudinal elevation called the ***medial eminence***. The eminence is bounded laterally by the ***sulcus limitans.*** The region lateral to the sulcus limitans is the ***vestibular area,*** which overlies the vestibular nuclei. The vestibular area lies partly in the pons and partly in the medulla.

The pontine part of the floor shows some features of interest in close relation to the sulcus limitans and the median eminence. The uppermost part of the sulcus limitans overlies an area that is bluish in colour and is called the ***locus coeruleus***. Deep to the locus coeruleus, there is the nucleus coeruleus, which extends upwards into the tegmentum of the midbrain. It is regarded as part of the reticular formation.

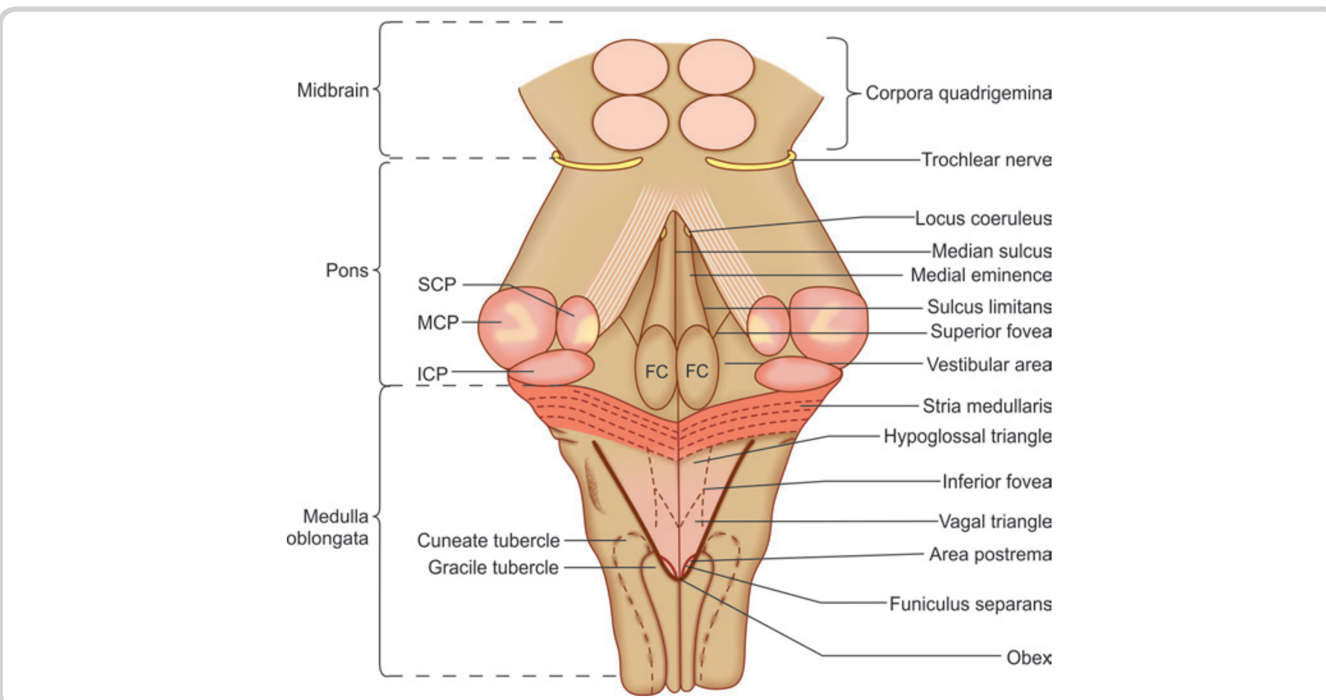

Figure 17.13: Structures in the floor of the fourth ventricle (SCP–Superior cerebellar peduncle; MCP–Middle cerebellar peduncle; ICP–Inferior cerebellar peduncle; FC–Facial colliculus)

Somewhat lower down, the sulcus limitans is marked by a depression, the ***superior fovea.*** At this level, the medial eminence shows a swelling, the ***facial colliculus***.

The medullary part of the floor also shows some features of interest in relation to the medial eminence and the sulcus limitans. The sulcus limitans is marked by a depression, the ***inferior fovea.*** Descending from the fovea, there is a sulcus that runs obliquely towards the middle line. This sulcus divides the median eminence into two triangles. These are the ***hypoglossal triangle***, medially and the ***vagal triangle,*** laterally. Between the vagal triangle (above) and the gracile tubercle (below), there is a small area called the ***area postrema.*** Finally, the two terms often used in relation to the medulla must be mentioned. The lowest part of the floor of the fourth ventricle is called the ***calamus scriptorius,*** because of its resemblance to a nib. Each inferolateral margin of the ventricle is marked by a narrow white ridge or ***taenia.*** The right and left taeniae meet at the inferior angle of the floor to form a small fold called the ***obex.*** The term obex is often used to denote the inferior angle itself.

Lateral Walls

The upper part of each lateral wall is formed by the superior cerebellar peduncle (Figure 17.14B). The lower part is formed by the inferior cerebellar peduncle and by the gracile and cuneate tubercles (Figure 17.14C and D).

Roof

The roof of the fourth ventricle is tent-shaped and can be divided into upper and lower parts, which meet at an apex (Figures 17.10 and 17.14A). The apex extends into the white core of the cerebellum. The upper part of the roof is formed by the superior cerebellar peduncles and the superior medullary velum (Figure 17.14A and B). The inferior part of the roof is devoid of nervous tissue in most of its extent. It is formed by a membrane consisting of ependyma and a double fold of pia mater, which constitutes the ***tela choroidea of the fourth ventricle*** (Figure 17.14A and C). Laterally, on each side, this membrane reaches and fuses with the inferior cerebellar peduncles. The lower part of the membrane has a large aperture in it. This is the ***median aperture*** of the fourth ventricle through which the ventricle communicates with the subarachnoid space in the region of the cerebellomedullary cistern. In the region of the lateral recess, the membrane is prolonged laterally and helps form the wall of the recess. The inferior medullary velum forms a small part of the roof in the region of the lateral dorsal recess (Figure 17.11). It may be noted that some authors describe the entire membranous structure, forming the lower part of the roof of the fourth ventricle, as the inferior medullary velum. The nodule is intimately related to the roof of the ventricle in the region of the median dorsal recess.

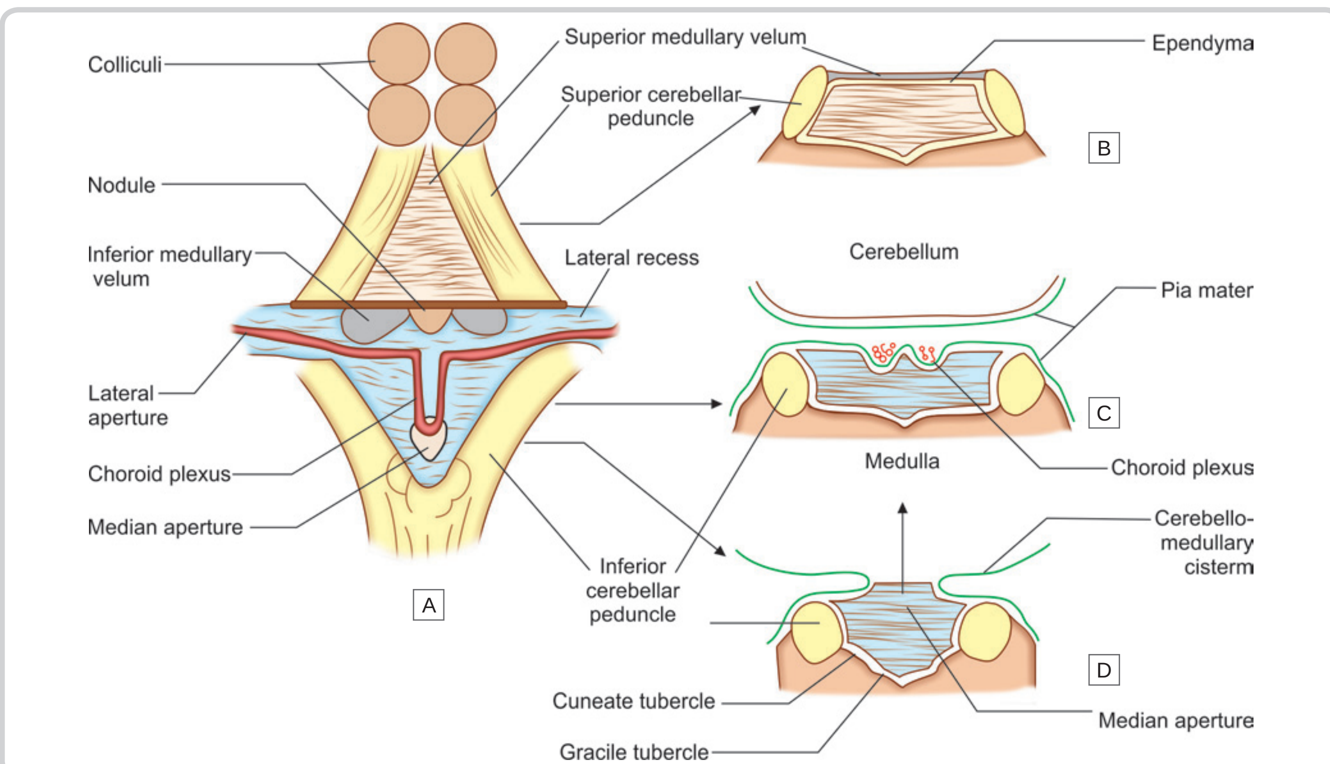

Figure 17.14: Schemes to illustrate the formation of the roof of the fourth ventricle. The bold horizontal line in 'A' represents the white core of the cerebellum. The part above this line represents the upper part of the roof and the part below the line represents the lower part of the roof. B to D, represent transverse sections across the ventricle at the levels indicated

Tela Choroidea and Choroid Plexuses of the Fourth Ventricle

As stated above, the ***tela choroidea of the fourth ventricle*** is made up of two layers of pia mater. The superior (or dorsal) layer lines the inferior vermis. On reaching the nodule (and more laterally, the inferior medullary velum), it is reflected on itself to form the inferior (or ventral) layer (Figure 17.10). When traced laterally, the dorsal layer is continuous with the pia mater covering the cerebellar hemispheres, while the ventral layer is continuous with the pia mater lining the medulla (Figure 17.14C).

The ***choroid plexuses of the fourth ventricle*** are similar in structure to those of the lateral and third ventricles. They lie within the folds of pia mater that form the tela choroidea and project into the cavity of the ventricle from the lower part of the roof (Figure 17.14C). Each plexus (right or left) consists of a vertical limb lying next to the midline and a horizontal limb extending into the lateral recess. The vertical limbs of the two plexuses lie side by side, so that the whole structure is T-shaped. The lower ends of the vertical limbs reach the median aperture and project into the subarachnoid space through it. The lateral ends of the horizontal limbs reach the lateral apertures and can be seen on the surface of the brain, near the flocculus. This choroid plexus is formed by posterior inferior cerebellar artery.

Clinical Correlation

- The ***area postrema*** is the site of the vomiting centre.
- ***Tumours*** (medulloblastomas) are common near the roof of the fourth ventricle.
- In ***Arnold Chiari deformity,*** the medulla and the tonsils of the cerebellum come to lie in the vertebral canal. Apertures in the roof of the fourth ventricle are blocked, leading to obstruction to flow of CSF and internal hydrocephalus. Cranial nerves arising from the medulla are stretched. This is a congenital anomaly. It is often associated with syringomyelia.

CEREBROSPINAL FLUID

The CSF fills the subarachnoid space. It also extends into the ventricles of the brain and the central canal of the spinal cord.

Site of Production

The choroid plexuses of the ventricles of brain secrete the CSF.

Circulation of Cerebrospinal Fluid

The CSF formed in each lateral ventricle flows into the third ventricle through the interventricular foramen (Figure 17.15). From the third ventricle, it passes through the aqueduct into the fourth ventricle. Here, it passes through the median and lateral apertures in the roof of this ventricle to enter the part of the subarachnoid space, which forms the cerebellomedullary cistern. From here, the fluid enters other parts of the subarachnoid space. In passing from the posterior cranial fossa into the upper (supratentorial) part of the cranial cavity, the CSF traverses the narrow interval between the free margin of the tentorium cerebelli and the brainstem. It leaves the subarachnoid space by entering the venous sinuses through arachnoid villi (Figure 17.15).

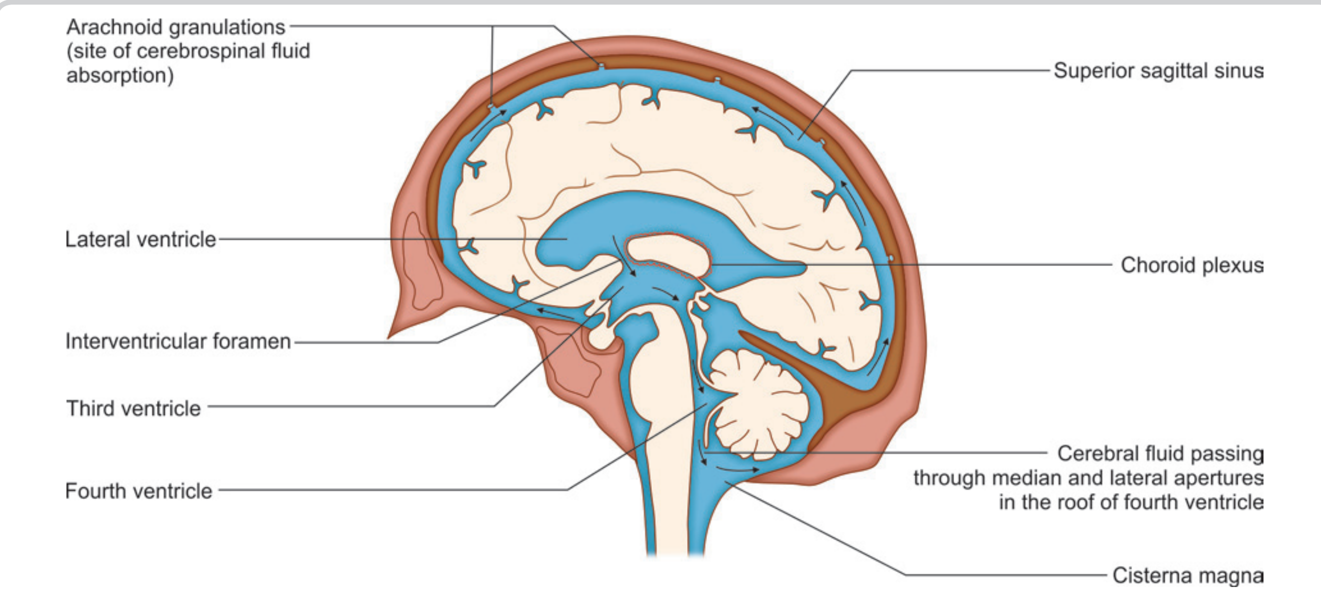

Figure 17.15: Scheme to show circulation of CSF

Characteristic Features of Cerebrospinal Fluid

- The total volume of CSF is about 140 mL, of which about 25 mL is in the ventricles. Daily production of CSF is around 1500 mL, this indicates that the CSF is constantly replaced.
- The normal pressure in supine position in lumbar subarachnoid space is 50–200 mm of water and in sitting position 200–250 mm of water.
- Its specific gravity ranges from 1.003 to 1.008.
- Glucose level is half of that of blood (40–60 mg %).
- Protein content is very low compared to plasma proteins (20–40 mg %) (Table 17.1).

Table 17.1 | Comparison of the Composition of CSF and Blood Plasma

Substance	CSF	Plasma
Protein	20–40 mg%	600 mg%
Glucose	40–60 mg%	100 mg%
Chloride	120 mEq/L	100 mEq/L
Calcium	2.5 mEq/L	4.5 mEq/L

Abbreviation: CSF, cerebrospinal fluid

Functions of Cerebrospinal Fluid

The CSF provides a fluid cushion, which protects the brain from injury. It probably also helps carry nutrition to the brain and remove waste products.

BLOOD-CEREBROSPINAL FLUID BARRIER

The tight junctions of the ependyma and other tissues of the choroid plexuses form an effective barrier between the blood and the CSF. This blood-CSF barrier allows selective passage of substances from blood to CSF, but not in the reverse direction. The arachnoid villi provide a valvular mechanism for flow of CSF into blood, without permitting back-flow of blood into the CSF.

Tanycytes and Specialized Areas of Ependyma

At some isolated sites in the walls of the third and fourth ventricles, there are patches of ependyma where the ependymal cells are tall, columnar, and ciliated and possess special histochemical properties. These cells are called ***tanycytes***. Some areas where these patches are found (in the human brain) are as follows:

- The ***subcommissural organ,*** located over the dorsal wall of the aqueduct, just behind the posterior commissure.
- The ***subfornical organ,*** present in relation to the roof of the third ventricle, just below the body of the fornix.
- The ***intercolumnar tubercle*** or the ***organ vasculosum,*** present in relation to the anterior wall of the third ventricle (in the region where the columns of the fornix diverge).
- In the floor of the fourth ventricle, the hypoglossal triangle is separated from the ***area postrema*** by a narrow ridge called the ***funiculus separans***. This ridge and the area postrema are lined by tanycytes.

Similar areas have been identified at various other sites in other species.

The functions attributed to tanycytes are:

- Secretion of neurochemical substances into CSF
- Secretion of CSF itself
- Transport of substances from CSF to underlying neurons or blood vessels
- They may also act as chemoreceptors

Clinical Correlation

Lumbar puncture

Samples of CSF are often required to assist in clinical diagnosis. They are obtained most easily by ***lumbar puncture***. In this procedure, a needle is introduced into the subarachnoid space through the interval between the third and fourth lumbar vertebrae.

Lumbar puncture, is useful for several purposes.

a. The pressure of CSF can be estimated, roughly, by counting the rate at which drops flow out of the needle; or more accurately, by connecting the needle to a manometer.
b. Samples of CSF can be collected for examination. The important points to note about CSF are its colour, its cellular content, and its chemical composition (specially the protein and sugar content).
c. Lumbar puncture may be used for introducing radio-opaque dye into the subarachnoid space for certain investigative procedures like myelogram. Drugs may also be injected for treatment.
d. Lumbar puncture can also be used to inject anaesthetic drugs into the subarachnoid space to act on the lower spinal nerve roots and render the lower part of the body insensitive to pain. This procedure, called **spinal anaesthesia**, is frequently used for operations on the lower abdomen or on the lower extremities.

Under exceptional circumstances, CSF may be obtained by ***cisternal puncture,*** in which a needle is passed into the cerebellomedullary cistern.

Papilloedema

The subarachnoid space extends up to the back of retina. An increased CSF pressure will result in backpressure on the retinal vessels, resulting in congestion and causing bulging of the optic disc, i.e. papilloedema.

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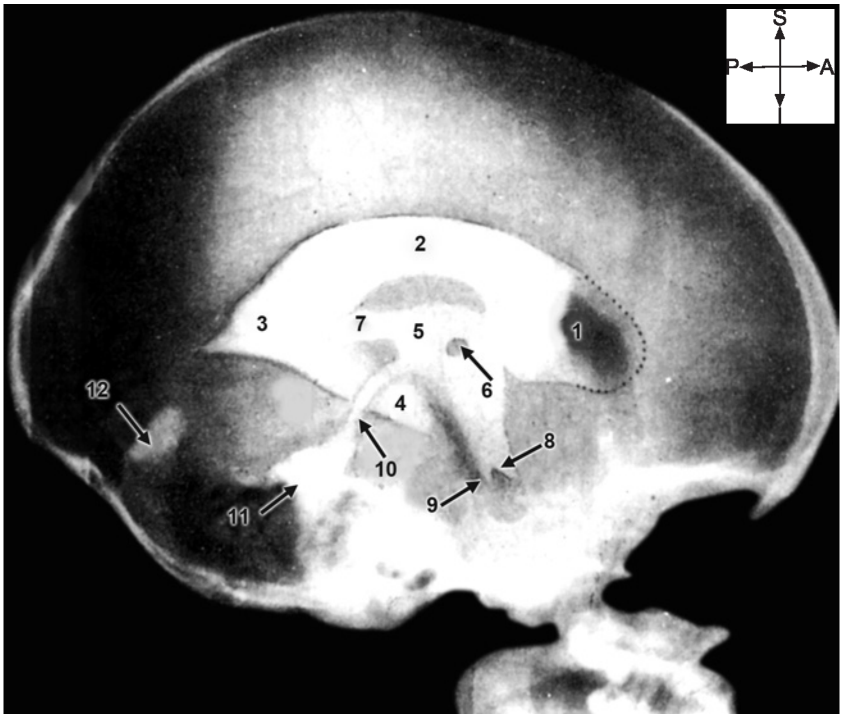

Figure 17.16: Ventriculogram. Lateral view. A radiograph of the head was taken after injecting a radiopaque dye into the ventricular system. The parts of the lateral ventricle seen are (1) anterior horn (part of which appears dark as air has entered it during injection), (2) central part, (3) posterior horn, and (4) inferior horn. In relation to the third ventricle, the structures seen are (5) suprapineal recess, (7) optic recess, (8) and infundibular recess (9). Interthalamic connexus is seen as a dark area (6). Other structures seen are aqueduct (10) and fourth ventricle (11). Some dye that has reached the cisterna magna through the apertures of the fourth ventricle is also seen (12)

This figure is reproduced by kind courtesy of Prof SC Srivastava

Quenkenstedt's Sign

It is positive when there is block in the subarachnoid space. When the internal jugular vein in the neck is compressed, the cerebral venous pressure in increased and absorption of CSF is inhibited. When there is a CSF block, there is no rise in manometer reading and queckenstedt sign is said to be positive.

Hydrocephalus

An abnormal increase in the quantity of CSF can lead to enlargement of the head in children. This condition is called ***hydrocephalus.*** Abnormal pressure of CSF leads to degeneration of brain tissue. Hydrocephalus may be caused by excessive production of CSF, by obstruction to its flow, or by impaired absorption through the arachnoid villi. It is classified as ***obstructive,*** when there is obstruction to flow of CSF from the ventricular system to the subarachnoid space or as ***communicating,*** when such obstruction is not present. Obstruction is most likely to occur where CSF has to pass through narrow passages, for example, the interventricular foramina, the aqueduct, and the apertures of the fourth ventricle. In each of the above instances, dilatation is confined to cavities proximal to the obstruction. Occasionally, meningitis may lead to obstruction of the narrow interval between the tentorium cerebelli and the brainstem. Meningitis may also lead to hydrocephalus by affecting the arachnoid villi, thus, hampering the reabsorption of CSF.

Cerebrospinal fluid and Injuries to the skull

The skull is frequently injured by blows with a heavy object and frequently in automobile accidents. Injury can be avoided by wearing a protective helmet.

- Direct injury leading to fractures of the skull can damage any area of the brain. CSF can flow out and parts of brain can herniate out of the skull.
- Even in the absence of a fracture, direct injury can throw the brain against the opposite wall of the skull injuring it. This is contracoup injury.
- In fractures of the base of the skull, CSF may flow into the nose. Hemorrhage may take place into brain tissue or into extradural space raising intracranial tension.

Ventriculography

The ventricles of the brain can be studied in living subjects by taking radiographs, after injecting a radiopaque dye into the ventricular system (Figure 17.16). The procedure is called ventriculography (not done routinely). Parts of the ventricles can also be seen using computed tomography (CT) and magnetic resonanace imaging (MRI) scans.

Multiple Choice Questions

1. The lateral ventricle communicates with the third ventricle through
   A. Foramen of Magendie
   B. Foramen of Luschka
   C. Foramen of Monro
   D. Aqueduct of Sylvius
2. Which of the following lobes of the cerebrum is related to the inferior horn of the lateral ventricle?
   A. Frontal
   B. Parietal
   C. Temporal
   D. Occipital
3. The choroid plexus of which part of lateral ventricle is formed by posterior choroidal artery?
   A. Anterior horn
   B. Posterior horn
   C. Inferior horn
   D. Central part (body)
4. The bulb of the posterior horn is produced by
   A. Forceps minor
   B. Tapetum
   C. Forceps major
   D. Optic radiation
5. The roof of the inferior horn if formed by
   A. Optic radiation
   B. Stria terminalis
   C. Inferior longitudinal fasciculus
   D. Body of the fornix
6. The anterior wall of the third ventricle is formed by
   A. Optic chaisma
   B. Tuber cinereum
   C. Lamina terminalis
   D. Habenular commissure
7. The invagination of the pia mater forming the tela chroidea of the third ventricle occurs through the
   A. Median longitudinal fissure
   B. Transverse fissure
   C. Callosal sulcus
   D. Stem of lateral sulcus
8. Which of the following structures forms a part of the roof of the fourth ventricle?
   A. Stria medullares
   B. Facial colliculi
   C. Vestibular area
   D. Inferior medullary velum
9. Which of the following forms a part of the floor of the fourth ventricle?
   A. Stria terminalis
   B. Facial colliculus
   C. Frenulum veli
   D. Foramen of Magendie
10. The facial colliculus is formed by
   A. Facial nucleus with its fibres
   B. Abducent nucleus with its fibres
   C. Facial nucleus with fibres of abducent nerve
   D. Abducent nucleus with fibres of the facial nerve

Answers

1. C **2.** C **3.** D **4.** C **5.** B **6.** C **7.** B **8.** D **9.** B **10.** D

Chapter 18

Ascending and Descending Tracts

Specific Learning Objectives

At the end of learning, the student shall be able to:
- Specify the commencement, course and termination of various ascending tracts terminating in the cerebral cortex
- Specify the various methods of pain inhibition
- Specify the commencement, course and termination of the ascending tracts terminating in the brain stem and cerebellum
- Specify the commencement, course, termination and clinical anatomy of the pyramidal and extrapyramidal tracts terminating in the spinal cord
- Integrate various pathways for voluntary motor activity

INTRODUCTION

A tract may be defined as a collection of nerve fibres having the same origin, course, and termination. Tracts may be ascending or descending. They are usually named after the masses of grey matter connected by them. Thus, a tract beginning in the cerebral cortex and descending to the spinal cord is called the corticospinal tract, while a tract ascending from the spinal cord to the thalamus is called the spinothalamic tract. Tracts are also referred to as fasciculi.

ASCENDING TRACTS

Sensory modalities are either special senses or general senses. The special senses are olfaction, vision, taste, hearing and vestibular function. Afferent pathways of these sense organs are described in the Chapter 10.

The general senses are classified as follows:
- ***Exteroception:*** Sensations perceived by the body, arising from external world and include touch, pressure, vibration, pain, thermal sensation, itch and tickle, etc
- ***Proprioception:*** Sensations perceived by the body, generated by bodies own tissues and include perception of posture, joint position and movement, muscle contraction and stretch
- ***Interoception:*** Sensations perceived by the body, arising from internal world and include sensations from viscera like hunger, thirst, bladder fullness, urge to defecate, etc.

Afferent impulses from the trunk and limbs are conveyed to the spinal cord in spinal nerves whilst those from the head are carried to the brain in cranial nerves. Ascending tracts related to the conscious general senses consist of a sequence of three neurons that extends from peripheral receptor to the cerebral cortex. These are often referred to as primary, secondary and tertiary neurons or first-order neurons, second-order neurons and third-order neurons. Unconscious proprioception and some exteroception going to cerebellum consist of only two neurons, as also those terminating in brain stem.

The ascending tracts of the spinal cord and brainstem represent one stage of multineuron pathways by which afferent impulses arising in various parts of the body are conveyed to different parts of the brain. The first order neurons of these pathways are usually located in spinal (dorsal nerve root) ganglia (Figure 18.1).

The neurons in these ganglia are unipolar (pseudo-unipolar). Each neuron gives off a peripheral process and a central process. The peripheral processes of the neurons form the afferent fibres of peripheral nerves. They end in relation to sensory end organs (receptors) situated in various tissues. The central processes of these neurons enter the spinal cord through the dorsal nerve roots.

In the case of the head (and other parts supplied by cranial nerves) the first order neurons are located in sensory ganglia situated on the cranial nerves. The central processes of these neurons end in relation to afferent nuclei of cranial nerves. The neurons in these nuclei constitute second-order neurons.

Having entered the spinal cord, the central processes, either terminate by synapsing with cells in spinal grey matter or may run upwards in the white matter of the cord to form ascending tracts. The majority of ascending tracts are, however, formed by axons of cells in spinal grey matter. These are second-order sensory neurons. The axons of the second order neurons may enter white matter on the same side, forming an uncrossed tract; or on the opposite side, forming a crossed tract.

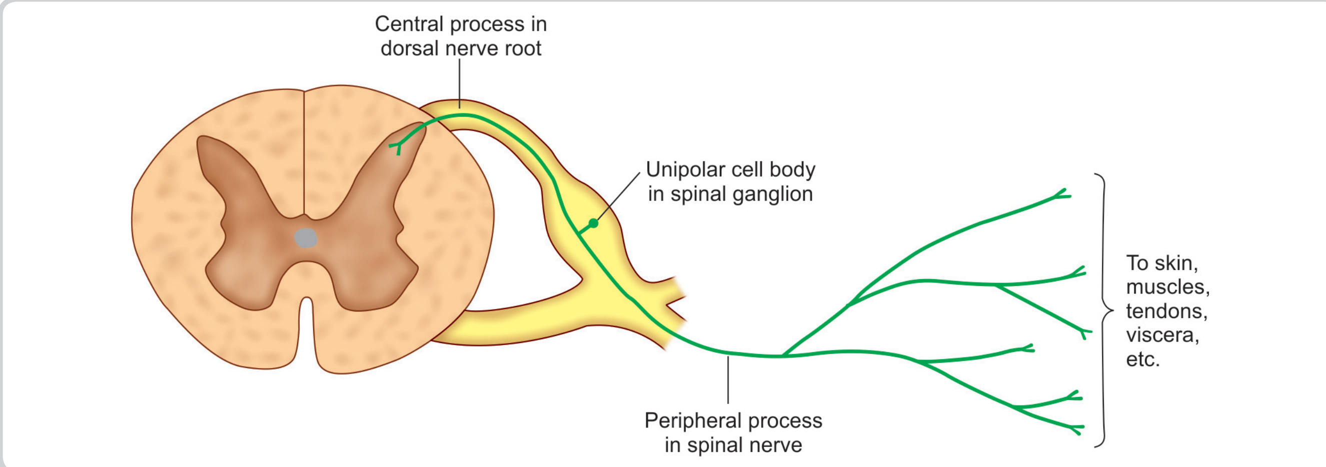

Figure 18.1: Scheme to show the typical arrangement of an afferent neuron

In the case of pathways that convey sensory information to the cerebral cortex, the second order neurons end by synapsing with neurons in the thalamus. Third-order sensory neurons located in the thalamus carry the sensations to the cerebral cortex.

Only those afferent impulses which reach the cerebral cortex are consciously perceived. One exception to this may be perception of some degree of pain in the thalamus. Afferent impulses ending in the cerebellum or in the brainstem influence the activities of these centres.

ASCENDING TRACTS PROJECTING TO CEREBRAL CORTEX

The ascending tracts carrying general senses and projecting to the cerebral cortex can be classified as follows:

- ***The posterior column medial lemniscus pathway:*** These are fibres carrying:
  - Proprioceptive information that convey the sense of position and of movement of different parts of the body
  - The ability to localize exactly the part touched (tactile localisation), the ability to recognize as separate two points on the skin that are touched simultaneously (tactile discrimination), and the ability to recognize the shape of an object held in the hand (stereognosis). from the trunk and limbs
  - The sense of vibration
- ***The anterolateral spinothalamic pathway:*** These are fibres carrying pain, temperature and coarse touch/pressure information from the trunk and limbs. The anterior part of the spinothalamic tract carries sensations of crude touch and pressure, while the lateral part carries sensations of pain and temperature
- ***The trigeminal lemniscus:*** These are fibres carrying all modalities of general senses from the head region.

Posterior Column-Medial Lemniscus Pathway

Posterior Column

The fasciculus gracilis and fasciculus cuneatus occupy the posterior funiculus of the spinal cord and are, therefore, often referred to as the posterior column tracts. They are formed by central processes of neurons located in dorsal nerve root ganglia, i.e., by first-order sensory neurons (Figure 18.2).

Somatotopic lamination: The fibres derived from the lowest ganglia are situated most medially; while those from the highest ganglia are most lateral (Figure 18.3). The fasciculus gracilis, which lies medially is, therefore, composed of fibres from the coccygeal, sacral, lumbar and lower thoracic ganglia; while the fasciculus cuneatus which lies laterally consists of fibres from upper thoracic and cervical ganglia. The fibres of these fasciculi extend upwards as far as the lower part of the medulla. Here the fibres of the gracile and cuneate fasciculi terminate by synapsing with neurons in the nucleus gracilis and nucleus cuneatus respectively.

Medial Lemniscus

The neurons of the gracile and cuneate nuclei are second-order sensory neurons. Their axons run forward and medially (as internal arcuate fibres) to cross the middle line in the lower medulla. The crossing fibres of the two sides constitute the sensory decussation (or lemniscal decussation). Having crossed the middle line, the fibres turn upward to form a prominent bundle called the medial lemniscus. The medial lemniscus runs upwards through the medulla, pons and midbrain to end in the thalamus (ventral posterolateral nucleus).

Somatotopic lamination: The fibres of lower half of the body lie more anteriorly than that of the upper half of the body in the medulla. They undergo a 90° rotation along

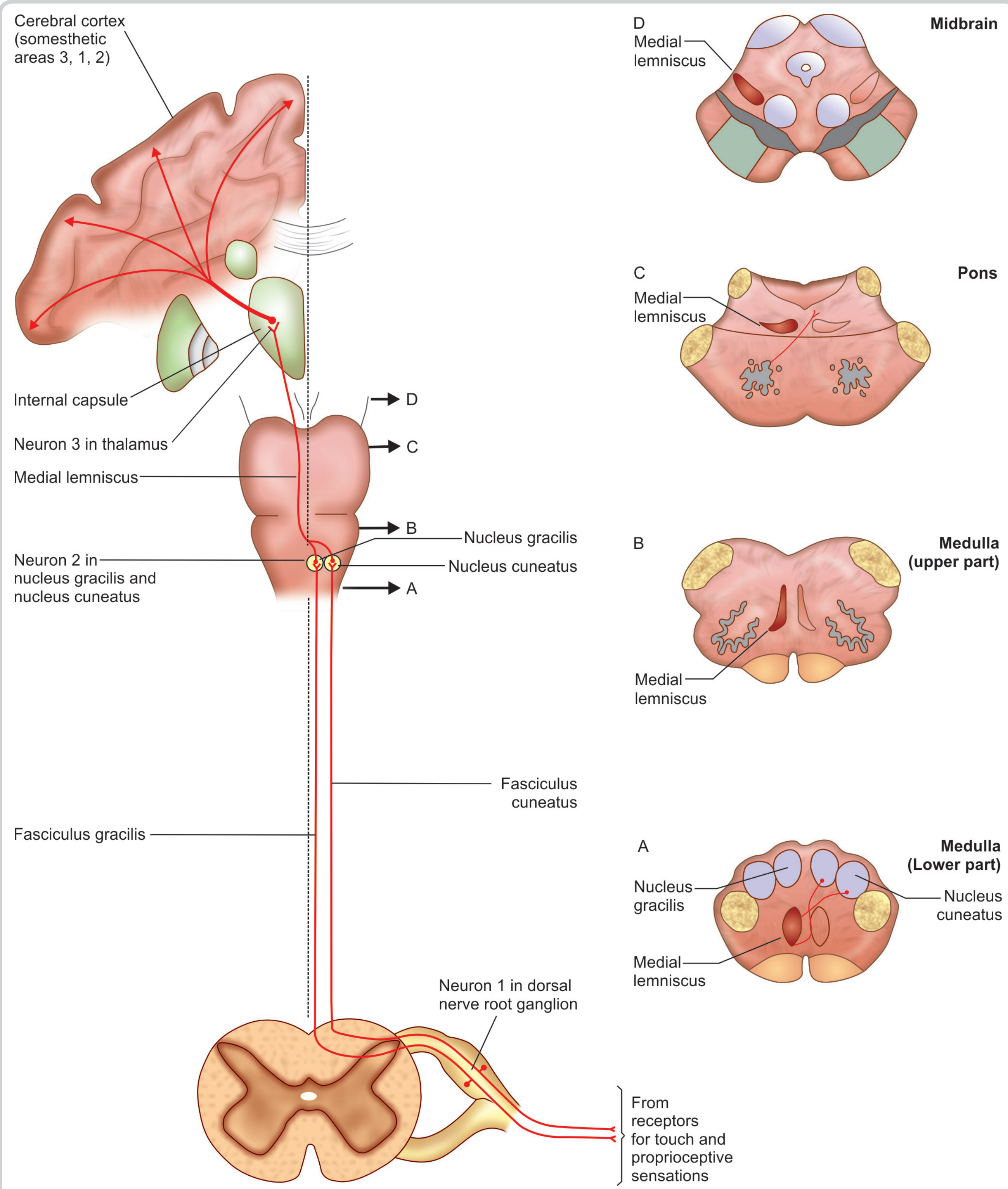

Figure 18.2: Main features of the posterior column medial lemniscus pathway

their own long axis so that, in the pons, the fibres of upper half of the body lie more laterally than the fibres of lower half of the body. They undergo a further 90° rotation along their own long axis so that, in the midbrain, the fibres of upper half of the body lie more anteriorly than the fibres of lower half of the body.

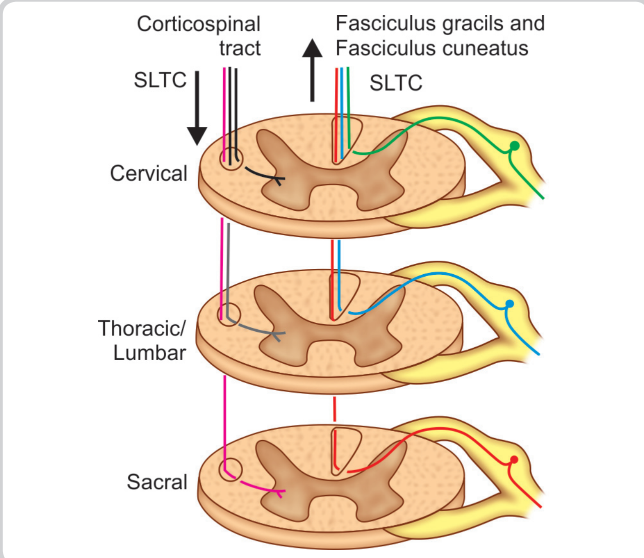

Figure 18.3: Scheme to show the pattern of lamination of the corticospinal and posterior column tracts (SLTC: Sacral, Lumbar, Thoracic, Cervical)

Superior Thalamic Radiation

Third-order sensory neurons located in the ventral posterolateral nucleus of the thalamus give off axons that pass through the internal capsule and the corona radiata to reach the somatosensory areas of the cerebral cortex. Fibres from lower half of the body terminate higher up on the postcentral gyrus than those from the upper half of the body (inverted sensory homunculus).

Anterolateral Spinothalamic Pathway

- The first-order neurons of this pathway are located in spinal ganglia. The central processes of these neurons enter the spinal cord and terminate in relation to spinal grey matter. Those fibres that carry pain sensation may ascend in the dorsolateral tract (situated near the tip of the dorsal grey column) for one or more segments before ending in grey matter.

Clinical Correlation

Large-diameter afferents are excitatory to the neurons of lamina IV, from which spinothalamic fibres arise, and to interneurons in the substantia gelatinosa. In contrast, fine non-myelinated pain afferents are excitatory to the neurons of lamina IV but inhibitory to substantia gelatinosa. The axons of substantia gelatinosa inhibit presynaptically the terminals of all afferents that synapse with neurons from which spinothalamic fibres arise (Figure 18.4) Therefore, activity in the pain afferents inhibits the interneurons, and so prevents them from inhibiting spinothalamic tract transmission. But impulses in the large-diameter afferents would close the gate to lamina IV in the interneurons by presynaptic inhibition and thus pain inhibition.

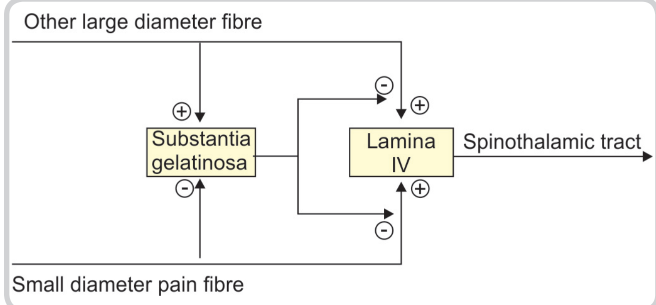

Figure 18.4: The sensory 'gate' mechanism in the spinal cord showing presynaptic inhibition by substantia gelatinosa

- The second order neurons of this pathway are located mainly in laminae IV, V, VI and VII. The axons of these neurons constitute the anterior and lateral spinothalamic tracts. They cross to the opposite side of the spinal cord in the white commissure.

Clinical Correlation

The pain and thermal sensations cross nearer the central canal and pass to the lateral spinothalamic tract (Figure 18.5), as opposed to crude touch and pressure that pass to anterior thalamic tract. Syringomyelia (destructive lesions of central canal) causes bilateral loss of pain and thermal sensations at the level of lesion. A high cervical syringomyelia, extending further upwards, causes progressive loss of pain and thermal sensations first over the neck, then along the ophthalmic distribution of trigeminal nerve followed by maxillary division of trigeminal ***(Balaclava helmet syndrome)***. Mandibular division does not get involved as its nucleus lies in the open part of medulla oblongata.

The fibres for the anterior spinothalamic tract enter the anterior funiculus where they lie medial to emerging fibres of ventral nerve roots. The fibres for the lateral spinothalamic tract enter the lateral funiculus. The two tracts form one continuous band that runs up the spinal cord.

Clinical Correlation

Cordotomy

Sometimes a patient may be in severe pain that cannot be controlled by drugs. As an extreme measure pain may be relieved by cutting the lateral spinothalamic tracts. The operation is called cordotomy. The ligamentum denticulatum serves as a guide to the surgeon. For relief of pain the incision is placed anterior to this ligament (anterolateral cordotomy) so as not to involve lateral corticospinal tract, responsible for skilful voluntary movement, that lies posteriorly.

Pain can also be relieved by cutting the posterior nerve roots in the region. This operation is called posterior rhizotomy.

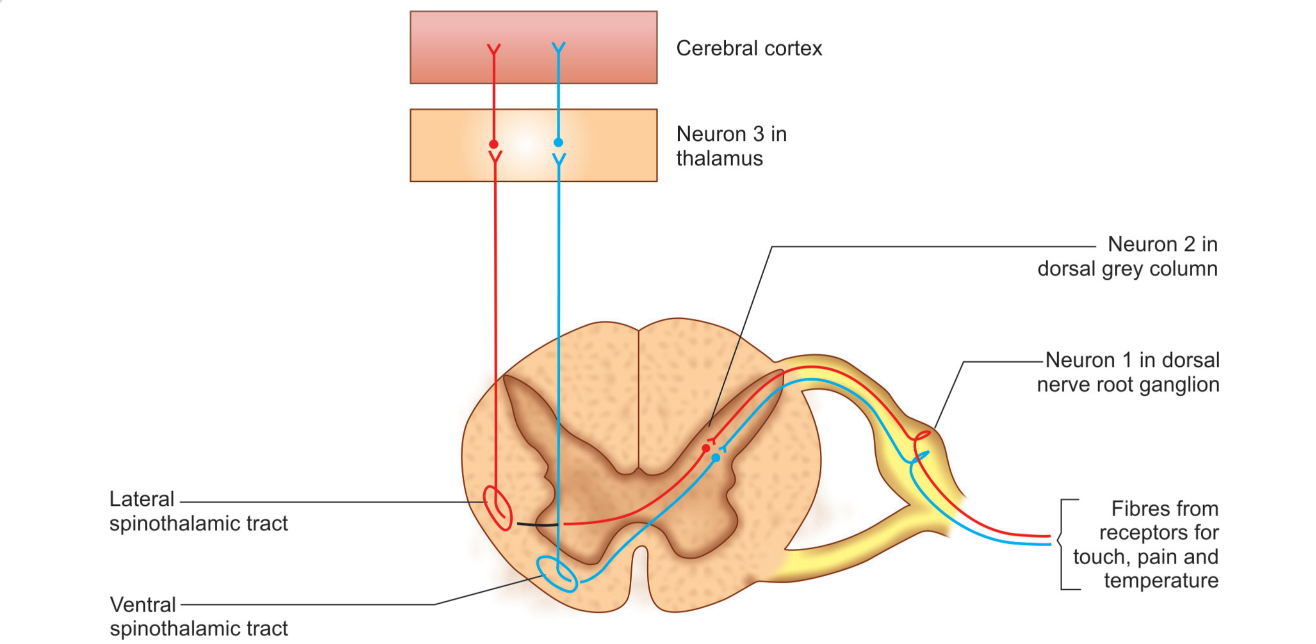

Figure 18.5: Scheme to illustrate the main features of the spinothalamic pathways

Somatotopic lamination: The sacral fibres lie outermost, followed by lumbar, thoracic and cervical, which is innermost (Figure 18.6). Apart from somatotopic lamination, mediolaterally the fibres of anterolateral spinothalamic pathways carry fibres subserving pressure, crude touch, pain and temperature sensations.

On reaching the medulla the two tracts separate. The anterior spinothalamic tract joins the medial lemniscus and travels through it to the thalamus. The lateral spinothalamic tract runs through the brainstem as a separate bundle called the spinal lemniscus which ends in the ventral posterolateral nucleus of the thalamus.

Clinical Correlation

Unlike the posterior column medial lemniscus pathway, these tracts give off numerous collaterals to reticular formation of brain stem. These collaterals also stimulate the ascending reticular activating system. A person can be easily awoken from a sleeping state by these pathways.
These collaterals are also responsible for pain inhibition via descending fibres from periaqueductal grey matter. Some fibres descend from the periaqueductal grey matter to nucleus raphe magnus of medulla, while others pass directly to the spinal cord. Descending fibres from medulla pass to the nucleus of the spinal tract of the trigeminal nerve and its continuation, the substantia gelatinosa, throughout the length of the spinal cord. Neurons in these sites secrete serotonin, GABA substance P, enkephalin and endorphin. All of these are intimately concerned with the control of pain inputs.

- Third-order sensory neurons are identical as the third order neuron of posterior column medial lemniscus pathway. The thalamus gives off axons that pass through the internal capsule and the corona radiata to reach

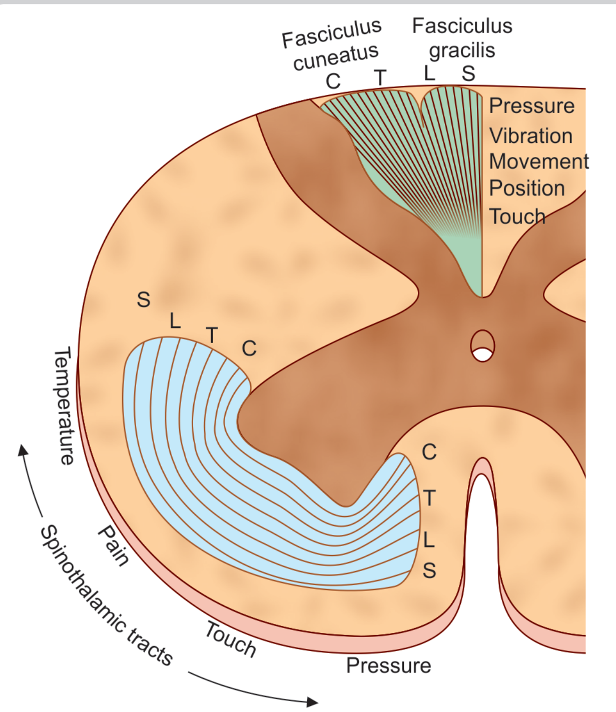

Figure 18.6: Scheme to show the pattern of lamination of the corticospinal and posterior column tracts

the somatosensory areas of the cerebral cortex. Fibres from lower half of the body terminate higher up on the postcentral gyrus than those from the upper half of the body.

Trigeminal Lemniscus

- The first-order neurons of this pathway are located in trigeminal ganglion. The central processes of these neurons enter the pons and terminate in relation to main sensory nucleus of trigenminal (for touch and pressure).

  The fibres that carry pain and thermal sesnstion may descend in the spinal tract of trigeminal before ending in grey matter in relation to that tract **(*nucleus of spinal tract of trigeminal nerve or spinal nucleus*)**. Cranio-caudally, this nucleus represents for mandibular, maxillary and ophthalmic divisions of trigeminal nerve.

  The first order neurons, for fibres that carry proprioceptive impulses from muscles of head, lie in the mesencephalic nucleus of the trigeminal nerve. They are exceptional in being the only first order neurons that lie within the brain. The central processes of the neurons in the nucleus end in the main sensory nucleus of the trigeminal nerve.
- The neurons in the main sensory and spinal nuclei of the trigeminal nerve are second order neurons. The axons cross to the opposite side and form a bundle called the trigeminal lemniscus. This lemniscus ascends to the thalamus (ventral posteromedial nucleus).
- Third-order neurons located in the thalamus carry the sensations to the sensory areas of the cerebral cortex low down in the post central gyrus. The representation in the cortex, from above down, are for ophthalmic, maxillary and mandibular divisions of trigeminal nerve (reverse of representation in spinal nucleus).

ASCENDING PATHWAYS ENDING IN BRAINSTEM

A number of tracts arising in spinal grey matter, and ending in masses of grey matter in the brainstem are described. They are as follows:

- ***The spinoreticular tracts*** begin from spinal neurons mainly in lamina VII (also V and VIII). The fibres are partly crossed and partly uncrossed. The fibres ascend in the ventrolateral part of the spinal cord, intermingling with spinothalamic tracts. They end in the reticular formation of the medulla and pons. The tract probably carries pain.
- ***The spino-olivary tract*** is also a crossed tract. It lies at the junction of the anterior and lateral funiculi of the spinal cord. The fibres of the tract end in accessory olivary nuclei
- ***The spinotectal tract*** connects the spinal grey matter to the superior colliculus. It is a crossed tract. It carries impulses that regulate reflex movements of the head and eyes in response to stimulation of some parts of the body.

ASCENDING PATHWAYS ENDING IN CEREBELLUM

These pathways carry proprioceptive impulses arising in muscle spindles, Golgi tendon organs, and other receptors to the cerebellum. They constitute the afferent component of reflex arcs involving the cerebellum, for control of posture. Recent investigations have shown that some exteroceptive sensations (e.g., touch) also reach the cerebellum through these pathways.

- The first-order neurons of these pathways are located in dorsal nerve root ganglia. Their peripheral processes end in relation to muscle spindles, Golgi tendon organs and other proprioceptive receptors. Some fibres are related to end organs concerned with exteroceptive sensations (touch and pressure). The central processes of the neurons concerned ascend in the posterior funiculi for varying distances before ending in spinal grey matter. Some of them ascend all the way to the medulla and end in the accessory cuneate nucleus.
- The second-order neurons of the pathway are arranged in a number of groups:
  - Neurons located in the dorsal nucleus (situated on the medial side of the base of the dorsal grey column in segments C8 to L3 of the spinal cord) give origin to fibres of the dorsal (posterior) spinocerebellar tract. This is an uncrossed tract lying in the lateral funiculus. It begins in the lumbar segments of the spinal cord and ascends to the medulla where its fibres become incorporated in the inferior cerebellar peduncle and pass through it to reach the vermis of the cerebellum (Figure 18.7).
  - The neurons giving origin to the ventral (anterior) spinocerebellar tract are located in the junctional area between the ventral and dorsal grey columns (laminae V, VI, VII) in the lumbar and sacral segments of the cord. Some of the neurons concerned may lie in the ventral grey column. The fibres of this tract are predominantly crossed. They ascend in the lateral funiculus, anterior to the fibres of the dorsal spinocerebellar tract, and pass through the medulla and pons. At the lower midbrain, the fibres turn downward to enter the superior cerebellar peduncle through which they reach the vermis of the cerebellum bilaterally (Figure 18.7).

    From a functional point of view both the ventral and dorsal spinocerebellar tracts are concerned

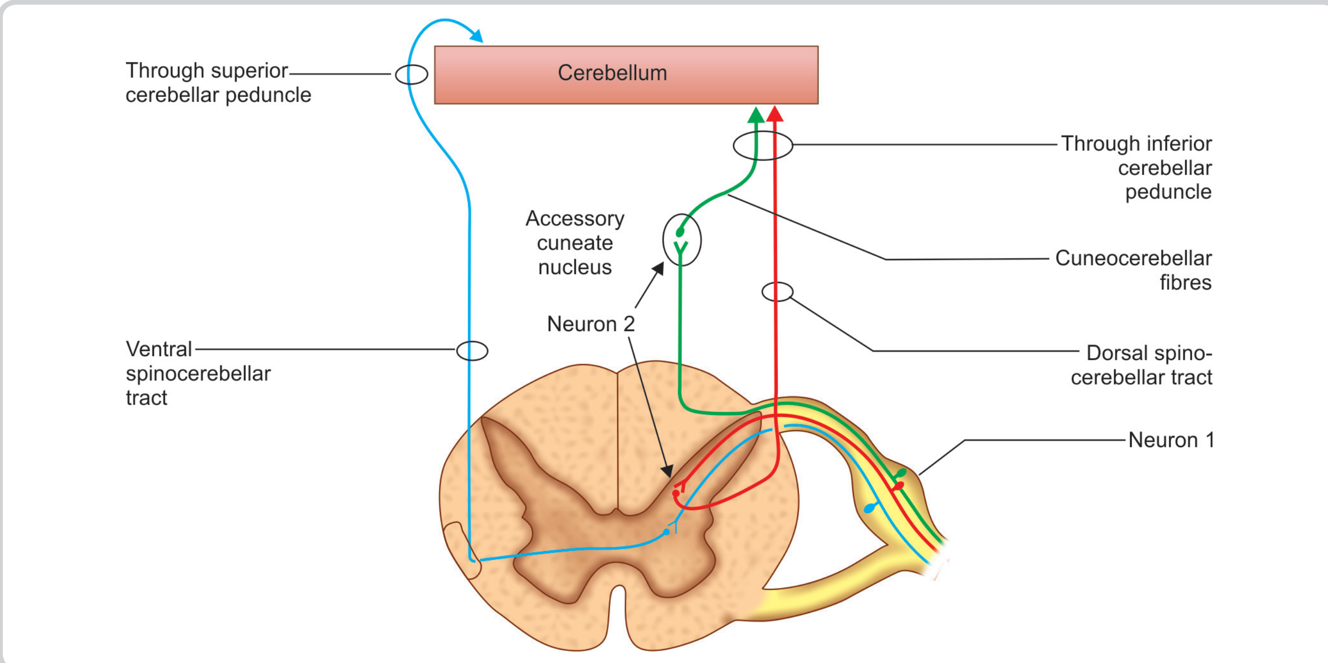

Figure 18.7: Scheme to show the main features of the spinocerebellar pathways

mainly with the lower limbs and trunk. The dorsal tract carries impulses concerned with fine coordination of muscles controlling posture, and with movements of individual muscles. On the other hand the ventral tract is concerned with movements of the limb as a whole.

- The central processes of some first order neurons (related to cervical segments) reach the accessory cuneate nucleus in the medulla. Second-order neurons lying in this nucleus give origin to posterior external arcuate fibres which enter the inferior cerebellar peduncle (of the same side) to reach the cerebellum. This cuneocerebellar tract carries impulses from the upper limb. It may be regarded as the forelimb equivalent of the dorsal spinocerebellar tract.

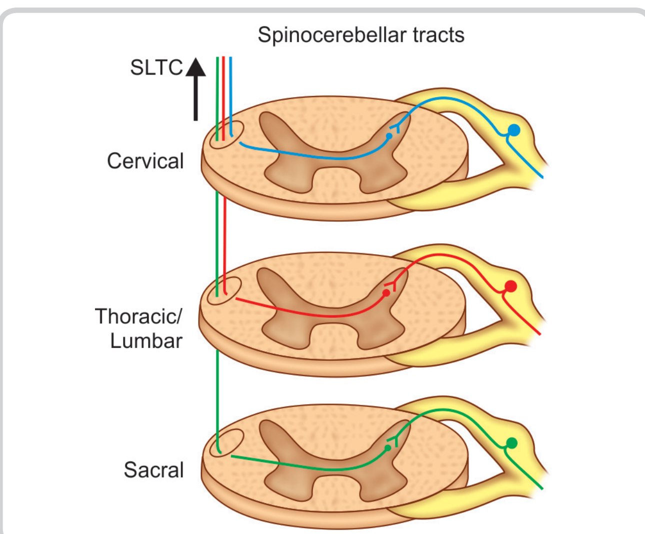

Figure 18.8: Scheme to show the pattern of lamination of the spinocerebellar tracts
(SLTC: Sacral, Lumbar, Thoracic, Cervical)

- ***Rostral spinocerebellar pathway:*** This tract arises from spinal grey matter in cervical regions of the spinal cord. The neurons of origin lie in the lower four cervical segments (lamina VII). Most fibres of the pathway are uncrossed. They reach the cerebellum through the inferior and superior cerebellar peduncles. This pathway is regarded, functionally, as the forelimb equivalent of the ventral spinocerebellar tract.

- ***Somatotopic lamination of spinocerebellar tracts:*** The fibres from sacral regions are outermost, followed by lumbar, etc (Figure 18.8).

DESCENDING TRACTS

Descending motor pathways can be classified as per their origin and termination.

Fibres starting from cerebral cortex or corticofugal fibres could terminate in:

- The spinal cord (passing through the pyramids of medulla oblongata, hence called ***pyramidal tract***), which is responsible for skilful, voluntary motor activity
- The motor brain stem nuclei, the ***corticonuclear tract*** (the cranial nerve equivalent of pyramidal tract)
- Non-cranial nerve brainstem nuclei, which could act as intermediaries for fibres descending to spinal cord (***extrapyramidal tracts***)

- Other brainstem nuclei, which could act as intermediaries for fibres going to cerebellum. Fibres starting from cerebellum and going to cerebral cortex complete the ***cerebellar loop***. The cerebellar loop is responsible for fine co-ordination of motor activity
- Basal nuclei – Fibres starting from basal nuclei and going to cerebral cortex complete the ***basal nuclei loop***. The ***basal nuclei loop*** is responsible for reflex co-ordination of muscle tone and posture for smooth execution of skilful, voluntary motor activity.

The term "upper motor neurons" refers collectively to all the descending pathways that act upon the "lower motor neurons". Lower motor neurons are the alpha and gamma motor neurons that innervate the extrafusal and intrafusal muscle fibres, respectively, of skeletal muscle. The intrafusal muscle fibres (or muscle spindle) when stretched, sets up a reflex for contraction of more extrafusal muscle fibres for motor activity (the "gamma-alpha linkage"). Thus the "final common pathway" for motor activity is the alpha motor neuron, which can be stimulated by (a) pyramidal tract, (b) extrapyrimidal tracts and (c) muscle stretch reflex.

CORTICOSPINAL TRACT (PYRAMIDAL TRACT)

The corticospinal tracts are made up, predominantly, of axons of neurons lying in the motor area of the cerebral cortex (area 4). Some fibres also arise from the premotor area (area 6 and 8) and some from the somatosensory area (areas 3, 2, 1). A few fibres arise in the parietal association cortex (area 5 and 7). Few fibres of corticospinal tracts also start from occipital and temporal lobes. Thus, the pyramidal tract starts from all four neocortical lobes.

Somatotopic lamination: In the precentral gyrus (area 4), the head is represented lower down, followed by neck, upper limb, trunk and lower limb (inverted motor homunculus). The representation of region beyond knee and the perineal region is on the medial surface of the cerebral hemisphere in the anterior part of paracentral lobule.

From this origin fibres pass through the corona radiata to enter the internal capsule where they lie in the posterior limb. Cortico-nuclear fibres to the head region lies in the genu of the internal capsule (Figure 18.9).

Somatotopic lamination: The fibres for head are most anterior and for the lower limb are most posterior. So the inferior-to-superior representation in the motor cortex have become anterior-to-posterior. The fibres have undergone a 90° rotation, by the time they have reached the internal capsule.

After passing through the internal capsule, the fibres enter the crus cerebri (of the midbrain). They occupy the middle two-thirds of the crus (Figure 18.9). The medial one-sixth is occupied by frontopontine fibres on their way to cerebellum and the lateral one-sixth is by parieto, occipito and temporopontine fibres.

Somatotopic lamination: In the crus cerebri, the fibres for head are most medial and for the lower limb are most posterior. So the fibres have undergone a further 90° rotation, by the time they have reached the midbrain.

The fibres then descend through the ventral part of the pons. Here the fibres get scattered by the numerous pontine nuclei and the transversely running pontocerebellar fibres (Figure 18.9).

By the time the fibres reach the medulla, they have regrouped themselves to enter the pyramids in the upper part of the medulla (Figure 18.9). Near the lower end of the medulla about 80 percent of the fibres cross to the opposite side. (The crossing fibres of the two sides constitute the decussation of the pyramids.)

Somatotopic lamination: In the decussation, upper limb fibres decussate at a slightly higher level than the lower limb fibres.

Clinical Correlation

Diplegia

A strategic neuroglioma in the upper part of the decussation can cause a diplegia of upper limb. Also, a meningioma pressing upon the anterolateral part of lower medulla (beyond crossing of upper limb fibres, but before crossing of lower limb fibres), can cause ipsilateral paralysis of upper limb and contralateral paralysis of lower limb (crossed diplegia).

The fibres that have crossed in the medulla enter the lateral funiculus of the spinal cord and descend as the lateral corticospinal tract (Figure 18.9). The fibres of this tract terminate in grey matter at various levels of the spinal cord. Most of them end by synapsing with internuncial neurons in the bases of the dorsal and ventral grey columns (laminae IV to VII). The internuncial neurons carry the impulses brought by fibres of the tract to ventral horn cells. Some fibres of the tract terminate directly on ventral horn cells (lamina IX, dorsolateral, central and ventrolateral groups). The lateral corticospinal tracts are concerned with movement of the distal muscles of the limb.

Somatotopic lamination: The cervical fibres are most medial, followed by thoracic, lumbar and sacral (18.10).

The corticospinal fibres that do not cross in the pyramidal decussation, enter the anterior funiculus of the spinal cord to form the anterior corticospinal tract (Figure 18.9). On reaching the appropriate level of the spinal cord, the fibres of this tract cross the midline (through the anterior white commissure) to reach grey matter on the opposite side of the cord. Their manner of termination is similar to that of fibres of the lateral corticospinal tract. A few fibres of this tract terminate ipsilaterally, also. The

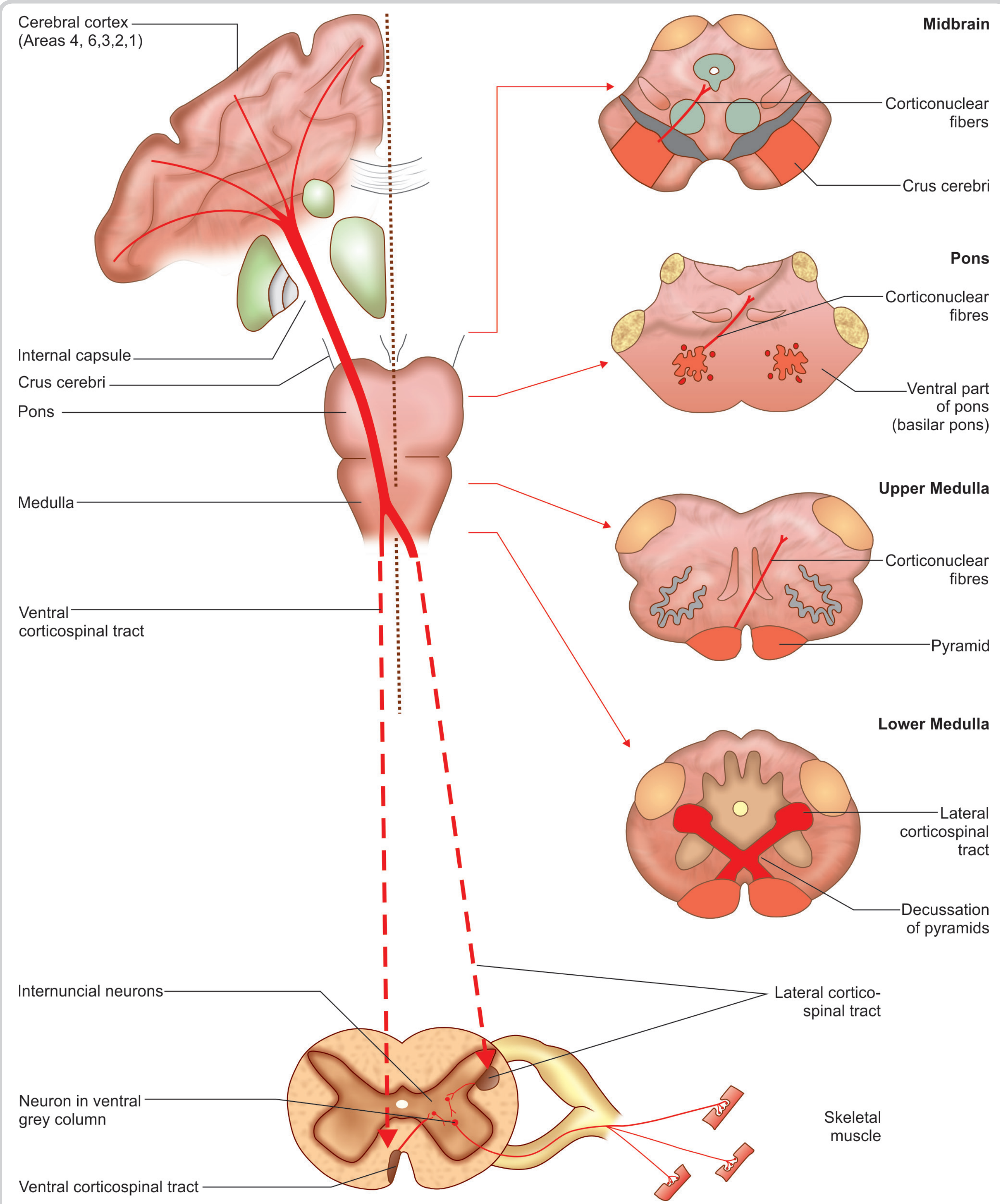

Figure 18.9: Scheme to show the course of the corticospinal tracts (Note the position of the tracts at various levels of the brainstem)

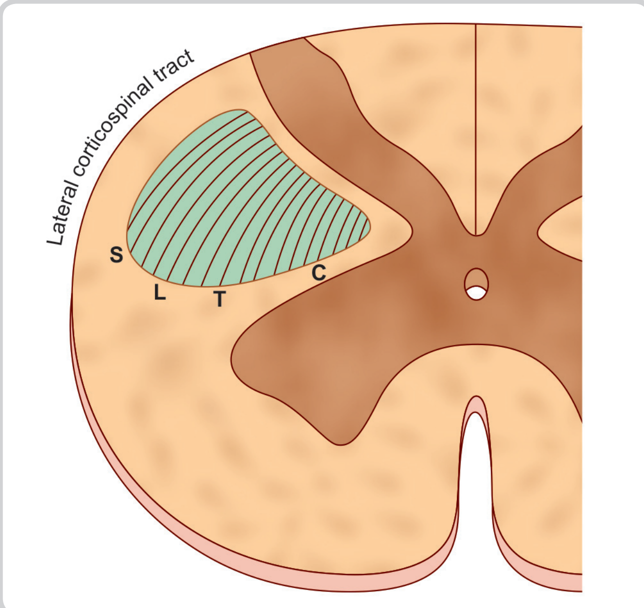

Figure 18.10: Somatotopic lamination of corticospinal tract (SLTC: Sacral, Lumbar, Thoracic, Cervical)

anterior corticospinal tracts are concerned with movement of the trunk and proximal (postural) muscles of the limb.

Fifty-five percent of the corticospinal fibres control the movements of upper limb, 20% for the movements of trunk and 25% for the movements of lower limb.

The cerebral cortex controls voluntary movement through the corticospinal tract. Interruption of the tract anywhere in its course leads to paralysis of the muscles concerned. As the fibres are closely packed in their course through the internal capsule and brainstem small lesions here can cause widespread paralysis.

The neurons that give origin to the fibres of the corticospinal tracts are often referred to as upper motor neurons in distinction to the ventral horn cells and their processes which constitute the lower motor neurons. Interruption of either of these neurons leads to paralysis, but the nature of the paralysis is distinctive in each case.

EXTRAPYRAMIDAL TRACTS

Descending fibres from brainstem nuclei to the spinal cord ***(extrapyramidal tracts)*** could start from:

- ***Red nucleus:*** Rubrospinal tract crosses to the opposite side in the ventral tegmental decussation and enters the lateral funiculus of the spinal cord. It favours flexor muscle tone (restricted to upper limb).

Clinical Correlation

Decorticate rigidity

Damage to the cerebral cortex or the pathways descending from the cortex produces decorticate rigidity. This is characterized by flexor rigidity of the upper limb and extensor rigidity in the lower limb. The flexion of the upper limbs is due to rubrospinal excitation of flexor muscles and by the lateral reticulospinal tract from medulla (both favor flexors). The extension of lower limbs is due to intact medial reticulospinal tract from pons (favor extensors) and vestibulospinal tract (favor extensors of lower limb).

Widespread haemorrhage in internal capsule may cause hemiplegia and unilateral decorticate rigidity.

- ***Tectum:*** Tectospinal tract crosses in the dorsal tegmental decussation and enters into the anterior funiculus of the spinal cord. It is responsible for visual spinal reflex.
- ***Vestibular nucleus:*** Vestibulospinal tract starts from the lateral vestibular nucleus. This uncrossed tract lies in the anterior funiculus of the spinal cord. This tract is an important efferent path for equilibrium and favours extensor muscle tone (in humans, generally of lower limb, for erect posture).
- ***Medial longitudinal fasciculus*** starting from other vestibular nuclei is called as medial vestibulospinal tract. It descends up to cervical part of spinal cord for reflex control of neck muscles to co-ordinate with eye movements.
- ***Reticular formation of pons:*** This nucleus generates it impulses itself without any control from higher centres. This medial reticulospinal tract carries crossed and uncrossed fibres that descend in the anterior funiculus of the spinal cord. The tract favours extensor muscle tone. This tract also carries fibres for supraspinal bladder control.

Clinical Correlation

Decerebrate rigidity

A complete transection of the brain stem between the superior and inferior colliculi of the midbrain permits the some extrapyramidal pathways to function independent of their input from higher centres. This lesion interrupts all input from the cortex and red nucleus. The excitatory pathways to postural extensor muscles via medial reticulospinal tract from pons and vestibulospinal tract remain intact. These tracts lead to hyperactivity in extensor muscles in all four limbs which is called decerebrate rigidity.

- ***Reticular formation of medulla:*** This lateral reticulospinal tract lies in the lateral funiculus of the spinal cord just medial to lateral spinothalamic tract. It carries fibres from repiratory centres for automatic breathing, from vasomotor centres for cardio acceleration. Fibres to lower motor neurons, which favour tone of flexor muscles, require intact higher centres (basal nuclei) for their activity.

Clinical Correlation

Ondine's curse

Persons afflicted with Ondine's curse or primary alveolar hypoventilation, classically suffer from respiratory arrest during sleep. There is a failure of autonomic control of breathing. It occurs in patients with severe brainstem lesions or bilateral high cervical cordotomy for relief from intractable pain. The pathway for automatic breathing is lateral reticulospinal tract which is immediately medial to lateral spinothalamic tract (carrying pain sensations). Voluntary breathing is unaffected, since lateral corticospinal tract lies behind the ligamentum denticulatum.

The name is in reference to Ondine, a water nymph, who had an unfaithful lover. Upon witnessing his adultery, she cursed him, stating, "You swore your faithfulness to me with every waking breath. As long as you are awake, you shall have your breath, but should you ever fall asleep, then you will forget to breathe!" Eventually, he fell asleep from sheer exhaustion, and died.

PATHWAY FOR VOLUNTARY MOTOR ACTIVITY

The idea for motor activity (Figure 18.11) comes from various parts of the brain culminating in the prefrontal cortex. The prefrontal cortex orchestrates the thoughts and actions in accordance with the desired goals. The impulses from here, along with those from emotional centres of limbic region and memory areas of temporal lobe, go to the sensory association areas of the brain. The association areas project to the premotor and motor areas for the intended activity.

The premotor and motor areas activate the basal nuclei loop for postural adjustment and the cerebellar loop for fine co-ordination by sending information to these centres about their motor plan.

The corticospinal (and corticonuclear for head region) executes the movement through the lower motor neuron (the "final common pathway). Proprioception from the muscles are sent to the spinal cord, and through the spinocerebellar and cuneocerebellar tracts, cerebellum receives the feedback. The cerebellum gives the feedback to the cerebrum.

If there is a discrepancy between the intention of movement and its performance, the inferior olivary nuclear complex comes into play. Cortico-olivary or cortico-rubro-olivary and spino-olivary pathways project to the inferior olivary nuclear complex. The climbing fibres of olivo-cerebellar pathway send a large, complex spike in the Purkinje cell that induces synaptic modification in parallel fibre-Purkinje cell synapses. These learning projects back to motor cortex as rectification signal for an improved motor performance.

The complex circuitry for execution of a simple motor activity justifies the adage: "For every single motor output from the central nervous system (CNS), there are 50 integrative circuits working in concordance!"

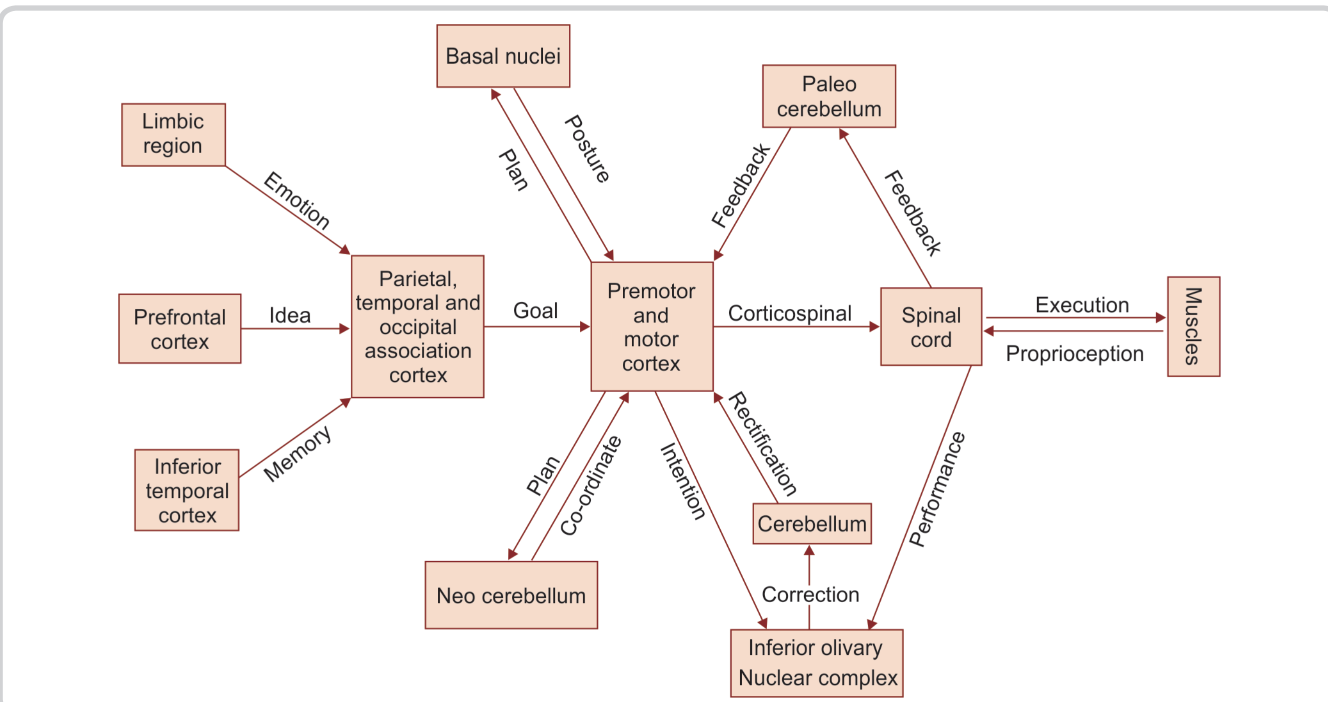

Figure 18.11: The complex pathway for execution of a simple motor activity

Multiple Choice Questions

1. Which of the following tracts is concerned with reflex head and neck movements in response to the stimulation of body parts?
   A. Spino-olivary
   B. Spinoreticular
   C. Spinotectal
   D. Spinovestibular
2. Which of the following funiculi of the spinal cord contains the fasciculus cuneatus?
   A. Anterior
   B. Lateral, anterior half
   C. Lateral, posterior half
   D. Posterior
3. Which type of sensations is carried by the spinal lemniscus?
   A. Pain
   B. Unconscious proprioception
   C. Vibration
   D. Tactile localization
4. The fibres of the medial reticulospinal tract begins from
   A. Medulla oblongata
   B. Pons
   C. Midbrain
   D. Diencephalon
5. The inability to perceive the texture and shape of an object occurs in lesion of
   A. Lateral spinothalamic tract
   B. Spinotectal tract
   C. Spinoreticular tract
   D. Fasciculus cuneatus
6. Which of the following tracts crosses the midline before its termination?
   A. Spinal tract of trigeminal nerve
   B. Posterior spinocerebellar tract
   C. Lateral vestibulospinal tract
   D. Anterior spinothalamic tract

Answers

1. C **2.** D **3.** A **4.** B **5.** D **6.** D

Chapter 19

Autonomic Nervous System

Specific Learning Objectives

At the end of learning, the student shall be able to:
- Specify the location of the cell bodies and axonal course and termination of preganglionic sympathetic and parasympathetic neurons
- Specify the location of the cell bodies and axonal course and termination of postganglionic sympathetic and parasympathetic neurons
- Name the neurotransmitters that are released by preganglionic autonomic neurons, postganglionic sympathetic neurons, postganglionic parasympathetic neurons, and the chemicals released by adrenal medullary cells
- Specify the role of the autonomic nervous system at select organs and glands
- Describe the enteric nervous system

INTRODUCTION

The ***autonomic nervous system (ANS)*** is made up of nerves supplying the viscera (and blood vessels) along with the parts of the brain and spinal cord related to them. The ANS includes the following:
- ***Areas for visceral function located in the cerebral hemispheres***: These are the structures in the limbic region of the brain. The hypothalamus, parts of the thalamus, and the prefrontal cortex are also involved in autonomic functions
- ***Autonomic centers in the brainstem***: These are located in the reticular formation and in the general visceral nuclei of cranial nerves
- ***Autonomic centers in the spinal cord***: These are located in the intermediolateral grey column
- ***Peripheral part of ANS***: This is made up of all autonomic nerves and ganglia throughout the body. Many of these are intimately related to cranial and spinal nerves.

Divisions of Autonomic Nervous System

The ANS is subdivided into three divisions:
- The ***sympathetic nervous system***
- The ***parasympathetic nervous system***
- The ***enteric nervous system***

The ANS like the somatic nervous system contains efferent as well as afferent fibres. The efferent fibres supply smooth muscles throughout the body. The influence may be either to cause contraction or relaxation. In a given situation, the sympathetic and parasympathetic nerves generally produce opposite effects. For example, sympathetic stimulation causes dilatation of the pupil, whereas parasympathetic stimulation causes constriction. In hollow viscera like the stomach or urinary bladder, parasympathetic stimulation produces movement and inhibits the sphincters. An opposite sympathetic effect is usually described. In the case of blood vessels, the influence on smooth muscle may result in vasoconstriction or in vasodilatation.

In addition to supplying smooth muscle, autonomic nerves innervate glands. Such nerves are described as ***secretomotor***. The secretomotor nerves to almost all glands are parasympathetic. The only exception are the sweat glands, which have a sympathetic supply.

EFFERENT AUTONOMIC PATHWAY

The efferent autonomic pathway, for innervation of smooth muscle or gland, always consists of two neurons that synapse in a ganglion (Figure 19.1). The first neuron carries the nerve impulse from the central nervous system (CNS)

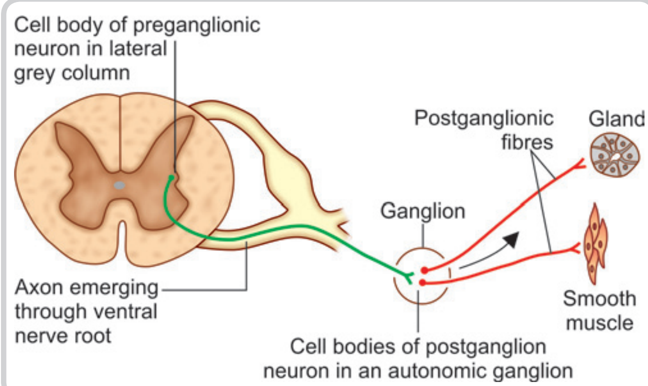

Figure 19.1: Scheme to show the typical arrangement of neurons in autonomic nervous system (general visceral efferent neurons)

Table 19.1 Location of cell bodies of ganglia in autonomic nervous system

Location	Sympathetic	Parasympathetic
Head	–	Ciliary, pterygopalatine, submandibular and otic
Neck	Superior, middle and inferior cervical	In the wall of the cervical viscera
Thorax	Paravertebral	Cardiac and pulmonary plexus
Abdomen	Paravertebral and plexus along the abdominal aorta (e.g. coeliac plexuses)	In the wall of the viscera (myenteric and submucosal)
Pelvis	Paravertebral and plexus along the internal iliac artery (hypogastric plexuses)	In the wall of the viscera (myenteric, submucosal and vesical)

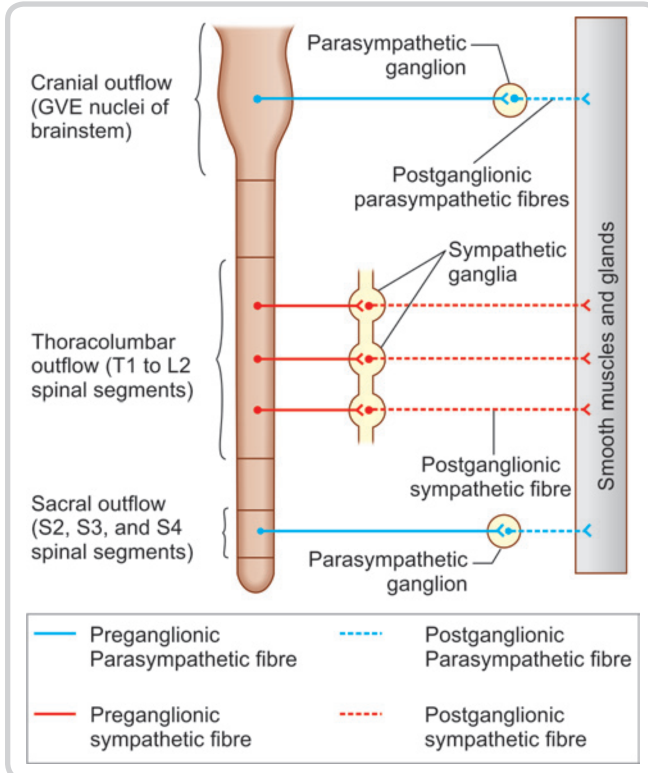

Figure 19.2: Schematic diagram to show the craniosacral outflow (parasympathetic) and thoracolumbar outflow (sympathetic)

to the ganglion and is called the ***preganglionic neuron***. The second neuron carries impulses from the ganglion to smooth muscle or gland and is called the ***postganglionic neuron***. The ANS, thus, has a general visceral efferent motor system, which controls and regulates smooth muscles and glands.

The location of cell bodies of ganglia in autonomic nervous system are shown in Table 19.1.

The number of postganglionic sympathetic neurons (or fibres) is much greater than that of preganglionic neurons, each preganglionic fibre synapsing with many postganglionic neurons. This results in considerable dispersal of the nerve impulse. A similar, but much lesser, dispersal of impulses also takes place in the parasympathetic nervous system. This is to be correlated with the fact that sympathetic stimulation produces widespread effects, whereas the effects of parasympathetic stimulation are much more localised.

SYMPATHETIC NERVOUS SYSTEM

Sympathetic Preganglionic Neurons

The cell bodies of sympathetic preganglionic neurons are located in the intermediolateral grey column of the spinal cord in the thoracic and upper two lumbar segments (Figure 19.2). Fibres arising from these neurons constitute the ***thoracolumbar outflow***. Their axons leave the spinal cord through anterior nerve roots to reach the spinal nerves of the segments concerned. After a very short course in the ventral primary rami, these fibres enter the white rami communicantes to reach the sympathetic trunk (Figure 19.3).

On reaching the sympathetic trunk, these fibres behave in one of the following ways (Figures 19.3 and 19.4):

- They may terminate in relation to cells of the sympathetic ganglion at the level concerned
- They may travel up or down the sympathetic trunk to terminate in ganglia at a higher or lower level
- They may leave the sympathetic trunk through one of its branches to terminate in a peripherally situated ganglion in the peripheral autonomic plexus (Figure 19.3).

Sympathetic Postganglionic Neurons

The sympathetic trunks (right and left) with a number of enlargements placed along its length, called ***sympathetic ganglia,*** form the postganglionic neurons. They are placed on either side of the vertebral column. Above, they extend to the base of the skull and below, to the coccyx. The number of ganglia is variable. Generally, there are 3 (superior, middle, and inferior) in the cervical region; 11 in the thoracic region; 4 in the lumbar region; and 4 in the sacral region, so that in all there are 22 ganglia on each trunk (Figure 19.5). The inferior cervical ganglion and the first thoracic are often fused to form a large ***stellate ganglion***.

The sympathetic trunks are connected to the spinal nerves by a series of communicating branches or ***rami communicantes***. These are of two types: white and grey. The white rami consist of myelinated fibres, while the

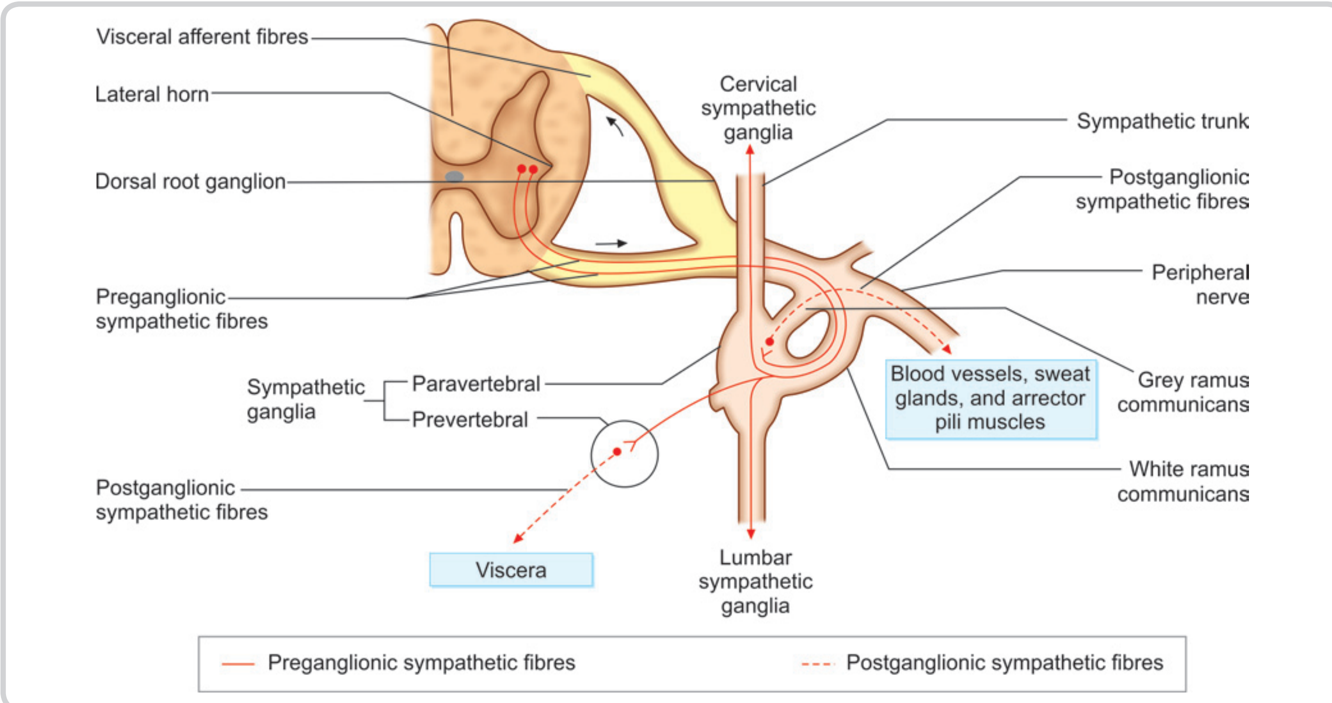

Figure 19.3: Grey and white rami connecting a spinal nerve to the sympathetic trunk and the fibres passing through them

grey rami are made up of unmyelinated fibres. The white rami carry fibres (originating in the spinal cord) from the spinal nerve to the sympathetic trunks. They are present only in the thoracic and upper lumbar regions. The grey rami carry fibres from the sympathetic trunk to spinal nerves. All spinal nerves receive grey rami. The fibres of the grey rami are distributed to peripheral tissues through the spinal nerves. The sympathetic trunks also establish communications with several cranial nerves through branches arising from the superior cervical ganglion.

In addition to communicating branches, the sympathetic trunks give off branches for supply of blood vessels and viscera. The visceral branches are directed medially (Figure 19.3) and take part in forming a series of autonomic plexuses in the thorax, abdomen, and pelvis. Branches to peripheral parts of the body follow one of two routes. Some branches from the sympathetic trunks reach blood vessels directly and form perivascular plexuses on them. One such branch arises from the cranial end of the superior cervical ganglion and forms a plexus around the internal carotid artery. Other sympathetic fibres reach blood vessels (specially in the limbs) after running for part of their course through spinal nerves and their branches (Figure 19.3).

Apart from supplying the blood vessels themselves, these sympathetic fibres innervate sweat glands and arrector pili muscles of the skin.

Axons arising from sympathetic postganglionic neurons behave in one of the following ways:

- The axons may pass through a grey ramus communicans to reach a spinal nerve. They then pass through the spinal nerve and its branches to innervate sweat glands and arrectores pilorum muscles of the skin in the region to which the spinal nerve is distributed.
- The axons may reach a cranial nerve through a communicating branch and may be distributed through it, as in the case of a spinal nerve.

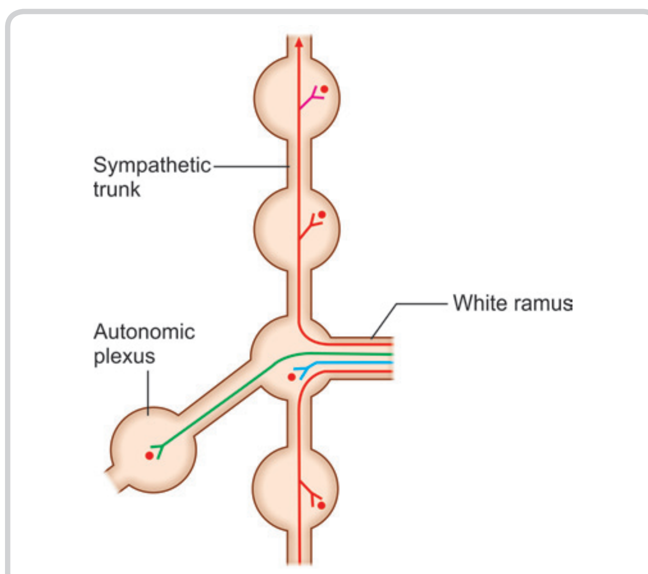

Figure 19.4: Mode of termination of sympathetic preganglionic neurons

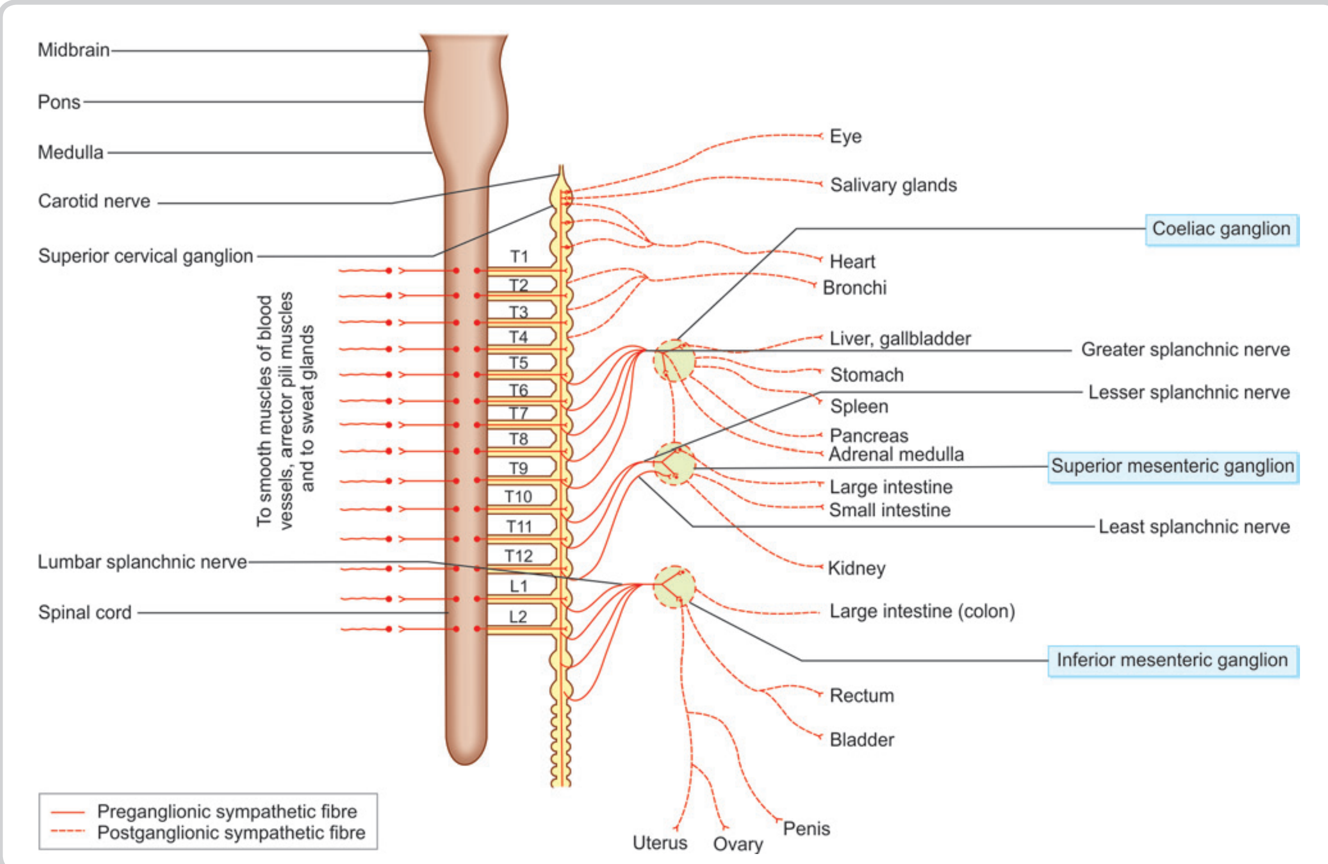

Figure 19.5: Schematic diagram of the sympathetic nervous system

- The axons may pass into a vascular branch and may be distributed to branches of the vessel. Some fibres from these plexuses may pass to other structures in the neighborhood of the vessel.
- Some axons, meant for innervation of blood vessels, travel for part of their course in spinal nerves or their branches and reach the vessels through vascular branches arising from these nerves. Many blood vessels in the peripheral parts of the limbs are innervated in this way.
- The axons of postganglionic neurons arising in sympathetic ganglia may travel through visceral branches and through autonomic plexuses to reach some viscera (for example, the heart).
- The axons of postganglionic neurons located in peripheral autonomic plexuses innervate neighboring viscera. These fibres often travel to the viscera in plexuses along blood vessels. For example, fibres for the gut travel along plexuses surrounding the branches of the coeliac, superior mesenteric, and inferior mesenteric arteries.

AUTONOMIC PLEXUSES

The visceral branches of sympathetic trunks help form various plexuses in the thorax, abdomen, and pelvis. In addition to sympathetic fibres, these plexuses contain parasympathetic fibres derived either from the vagus nerve or from pelvic splanchnic nerves. They also contain collections of neurons, which are often referred to as ganglia. In the thorax, there are ***superficial and deep cardiac plexuses*** in relation to the heart and the ***pulmonary plexuse***s in relation to the lungs (Figure 19.6). In the abdomen, there is a prominent ***coeliac ganglion*** on either side of the aorta. The two ganglia are interconnected by numerous fibres that form the ***coeliac plexus***. This plexus is closely related to the coeliac trunk and sends ramifications along its branches. Other plexuses (or ganglia) are related to the abdominal aorta, superior and inferior mesenteric arteries, and other branches arising from the aorta. The pelvis has a ***superior hypogastric plexus*** (often called the ***presacral nerve***) situated near the bifurcation of the aorta. When traced downwards, it divides into two ***inferior hypogastric plexuses*** (or ***hypogastric nerves***) related to each internal iliac artery (Table 19.2). Subsidiary plexuses run along branches of the internal iliac artery. Some plexuses are present in close relation to some viscera or even within their walls. The vesical plexus surrounds the urinary bladder. In the gut, there is a ***myenteric plexus*** (of Auerbach) between the muscle coats and a ***submucosal plexus*** (of Meissner).

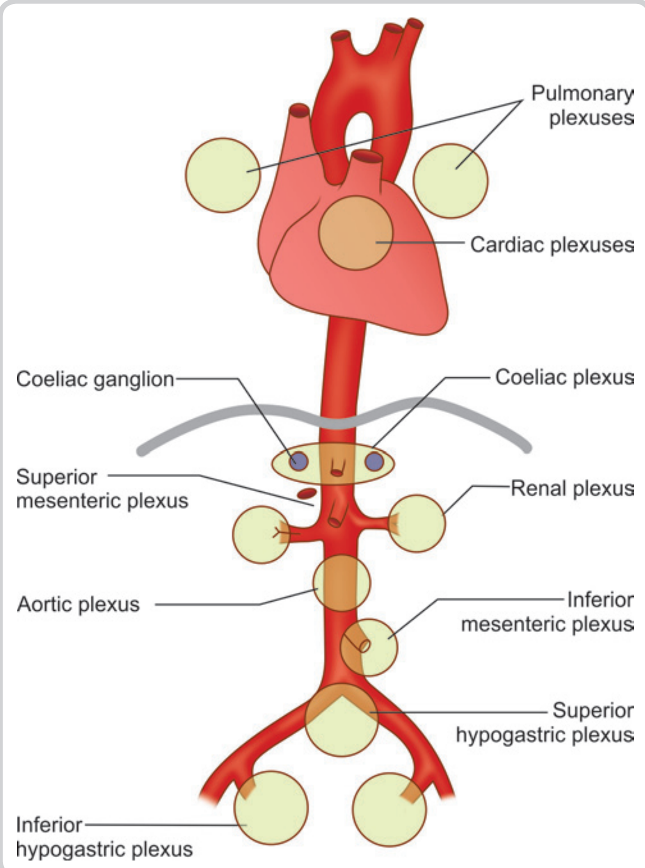

Figure 19.6: Schematic representation of the location of important autonomic plexuses of the thorax and abdomen

Table 19.2 | Autonomic Plexuses and Their Locations

Region	Autonomic plexuses
Thorax	Superficial and deep cardiac, pulmonary, and oesophageal
Abdomen	Coeliac, superior mesenteric, inferior mesenteric, and aortic
Pelvis	Superior and inferior hypogastric and pelvic

PARASYMPATHETIC NERVOUS SYSTEM

Parasympathetic Preganglionic Neurons

The parasympathetic preganglionic neurons are located in two distinct situations.

- The first group is located in the general visceral efferent nuclei of the brainstem. Axons arising in these nuclei constitute the ***cranial parasympathetic outflow*** (Figure 19.2). They pass through the third, seventh, ninth, and tenth cranial nerves to terminate in peripheral ganglia. The largest part of this outflow is constituted by the vagus nerve. Its fibres terminate in relation to postganglionic neurons located in thoracic and abdominal autonomic plexuses.

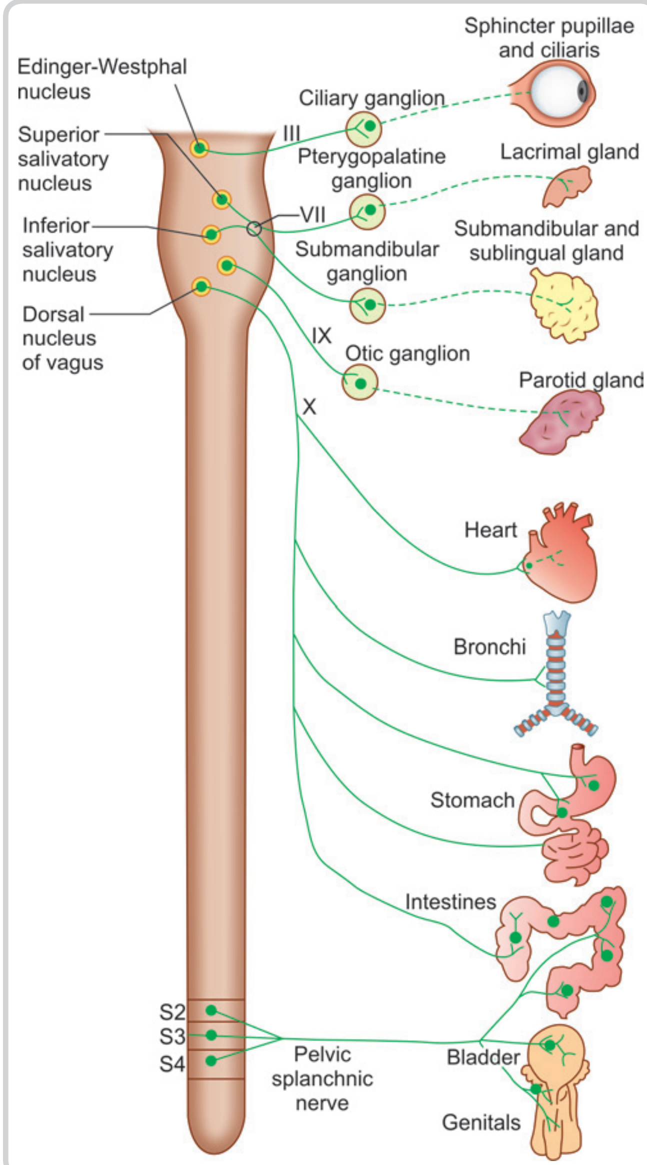

Figure 19.7: Craniosacral (parasympathetic) outflow

- The second group of parasympathetic preganglionic neurons is located in the second, third, and fourth sacral segments of the spinal cord (Figure 19.2). Their axons constitute the ***sacral parasympathetic outflow***. They emerge from the cord through the anterior nerve roots of the corresponding spinal nerves. The axons leave the spinal nerves to form the ***pelvic splanchnic nerves,*** which end in pelvic autonomic plexuses (Figure 19.7).

Parasympathetic Postganglionic Neurons

- Postganglionic neurons related to the third, seventh, and ninth cranial nerves are located in the ciliary, submandibular, pterygopalatine, and otic ganglia. Some subsidiary ganglia may be located in the vicinity of these ganglia.

- Postganglionic neurons related to the vagus are located in thoracic and abdominal autonomic plexuses, close to or within the viscera supplied (Figure 19.7). The axons arising from these postganglionic neurons innervate various thoracic and abdominal viscera, including the foregut and midgut.
- Postganglionic neurons related to the sacral parasympathetic outflow are located in pelvic autonomic plexuses. They innervate the pelvic viscera. They also supply the hindgut (rectum, the sigmoid colon, the descending colon), and the left one-third of the transverse colon.

NEUROTRANSMITTERS OF AUTONOMIC NEURONS

- The neurotransmitter acetylcholine is liberated at the terminals of preganglionic neurons, both sympathetic and parasympathetic (Figure 19.8)
- Acetylcholine is also liberated at the terminals of parasympathetic postganglionic neurons
- The neurotransmitters liberated at the terminals of sympathetic postganglionic neurons is noradrenalin. Cells of the adrenal medulla, which receive terminals of preganglionic sympathetic neurons and produce noradrenalin and adrenalin, may be regarded as modified sympathetic postganglionic neurons. It may be noted that cells of the sympathetic ganglia and of the adrenal medulla have a common embryological origin from the neural crest
- Postganglionic sympathetic neurons innervating sweat glands and some blood vessels of skeleted muscles are exceptional in that their terminals liberate acetylcholine.

AFFERENTS ACCOMPANYING AUTONOMIC PATHWAYS

The sensory neurons related to the ANS are general visceral afferent neurons, and their arrangement is similar to that of afferent fibres in cerebrospinal nerves. The neurons concerned are located in spinal ganglia or in sensory ganglia of cranial nerves. They carry impulses arising in viscera and in blood vessels, to the CNS. They may be associated with the parasympathetic as well as the sympathetic systems. Accordingly, the cell bodies of the neurons in question may be located in one of the following situations.

Afferents Related to the Cranial Part of Parasympathetic System

These are general visceral afferent fibres related to the glossopharyngeal and vagus nerves (Figure 19.9A). The cell bodies of the neurons concerned are located in sensory ganglia related to the cranial nerve in question. Their central processes terminate in the nucleus of the solitary tract.

Glossopharyngeal afferents carry sensations from the pharynx and posterior part of the tongue. They also innervate the carotid sinus and carotid body. Sensory fibres carried by the vagus innervate all organs to which its efferent fibres are distributed. The sensory fibres in the vagus are much more numerous than efferent fibres. Apart from carrying sensations, afferent fibres are also involved in various reflexes related to the organs concerned.

Afferents Related to the Sacral Part of Parasympathetic System

These afferents are peripheral processes of unipolar neurons located in the dorsal nerve root ganglia of the

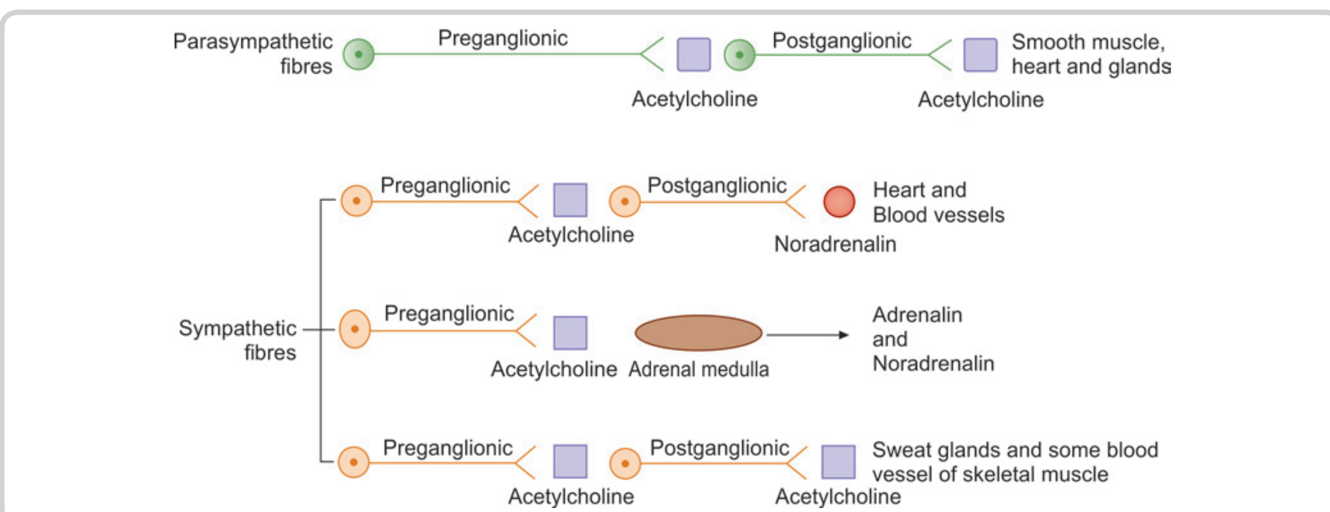

Figure 19.8: Neurotransmitters of autonomic neurons

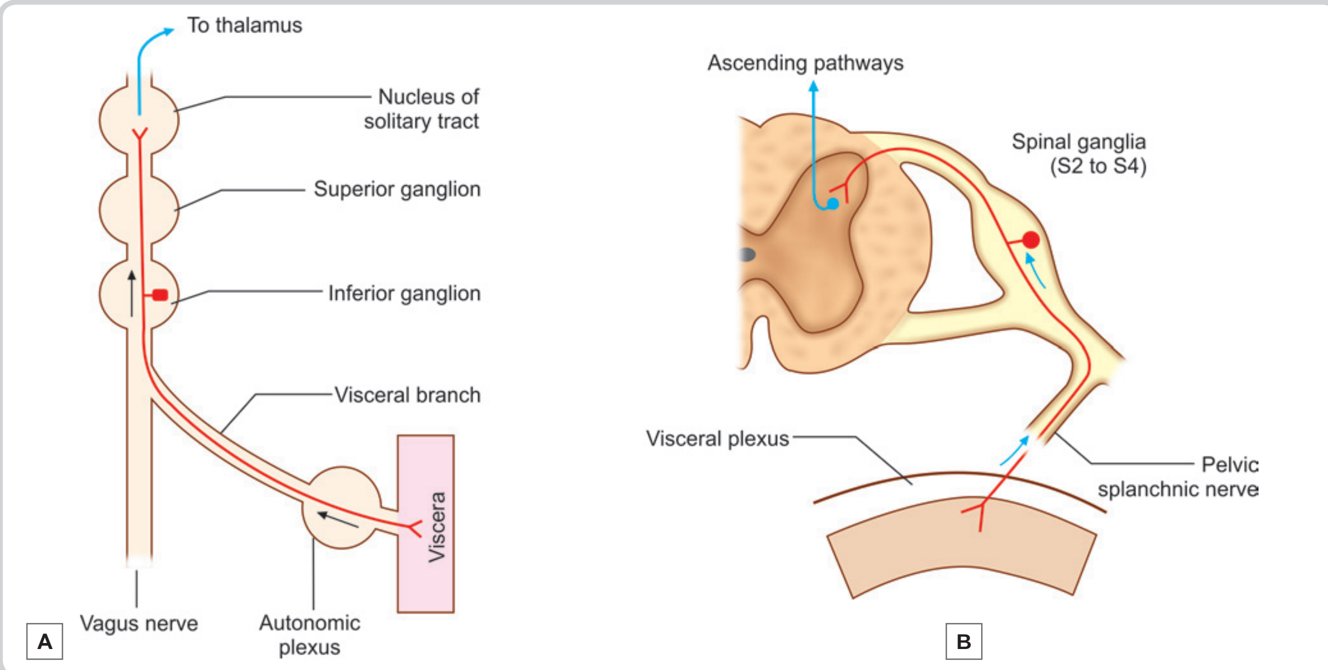

Figure 19.9: Arrangement of (**A**) afferent autonomic neurons related to the vagus and (**B**) pelvic splanchnic nerves

second, third, and fourth sacral nerves (Figure 19.9B). These fibres run through the pelvic splanchnic nerves to innervate pelvic viscera. The central processes of these neurons enter the spinal cord.

Afferents Related to Sympathetic Nervous System

Afferent fibres accompany almost all efferent sympathetic fibres. These afferent fibres are peripheral processes of unipolar neurons located in the spinal ganglia of spinal nerves T1 to L2 (or L3) (Figure 19.10).

Clinical Correlation

- Autonomic afferents are necessary for various visceral reflexes. Most of these impulses are not consciously perceived.
- Some normal visceral sensations that reach consciousness include those of hunger, nausea, distension of the urinary bladder or rectum, and sexual sensations. Sense of touch or pressure perceived by the tongue and pharynx and the sensation of taste are also visceral sensations.
- Under pathological conditions, visceral pain is perceived. This is produced by distension, by spasm of smooth muscle, or by anoxia. The pain is projected (referred) to that part of the body wall that is innervated by the same spinal segment (dermatome).
- Sensory impulses from the same organ may travel both along sympathetic and parasympathetic nerves. However, referred pain of cervical viscera is felt in the ear (glossopharyngeal and vagus); that of pelvic organs, including cervix, is referred to low back (S 2, 3, 4). The

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thoracic and abdominal organs (including uterus) project their referred pain to the dermatome equivalent to their sympathetic innervation.

ENTERIC NERVOUS SYSTEM

The entire length of gastroinestinal tract is supplied by sympathetic and parasympathetic parts of ANS. Apart from these, two different nerve plexuses are present in the gut wall.

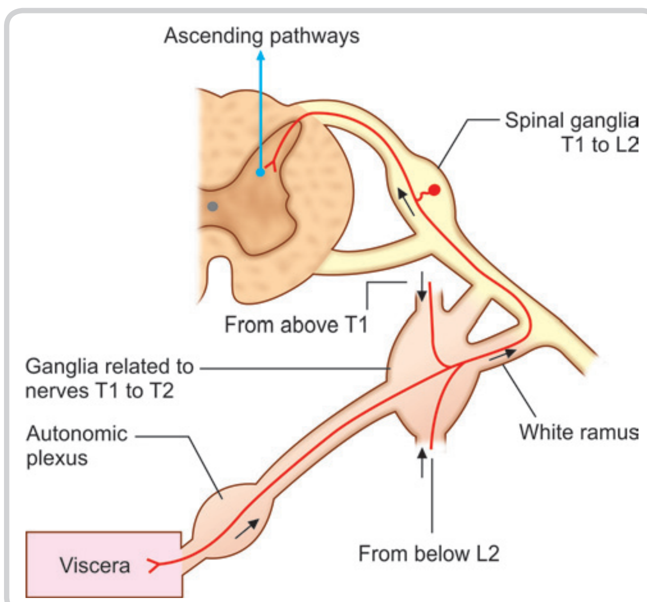

Figure 19.10: Afferent autonomic pathways involving sympathetic nerves

Although the presence of nerve plexuses in the wall of the gut containing neuronal somata in addition to nerve fibres, has been well known, their function has been obscure. Recent researches using immunochemical methods have revealed the presence of a large number of neuroactive substances in these plexuses. It has even been claimed that almost every neuroactive substance to be found in the CNS is also present in relation to the gut, suggesting much greater complexity of function of enteric plexuses than hitherto believed. The nerve plexuses of the gut are, therefore, now regarded as a third component of the ANS (the other two components being sympathetic and parasympathetic), which is referred to as the ***enteric nervous system***.

The enteric nervous system is located within the wall of the digestive tract, from the oesophagus to the anus. It is comprised of two well-organized neural plexuses:

- ***Myenteric plexus (of Auerbach)*** is located between longitudinal and circular layers of muscle. This is involved in control of gastrointestinal tract motility.
- ***Submucosal plexus (of Meissner)*** is located between the circular muscle and the luminal mucosa. This innervates the muscularis mucosae and thus regulates blood flow to the mucosa, movement of mucosa, absorption and secretive function of the lining epithelium.

The enteric nervous system contains sensory neurons, interneurons and motor neurons. It contains sensory neurons innervating receptors in the mucosa. Motor neurons control motility, secretion, and absorption. Interneurons integrate information from sensory neurons to the motor neurons.

Although the enteric nervous system can function autonomously, normal digestive function requires communication between the CNS and the enteric nervous system. It is the parasympathetic stimulation that increases overall degree of activity of the gastrointestinal tract. This also increases the rate of secretion of the gastrointestinal glands. Strong sympathetic stimulation inhibits peristalsis and increases the tone of the sphincters. This results in slowing of propulsion of food through the tract and decreased secretion as well.

AUTONOMIC NERVE SUPPLY OF SOME IMPORTANT ORGANS

The Eyeball

The ***sphincter pupillae*** is supplied by parasympathetic nerves. The preganglionic neurons concerned are located in the Edinger-Westphal nucleus. Their axons travel through the oculomotor nerve and terminate in the ciliary ganglion. Postganglionic neurons are located in this ganglion. Their axons supply the sphincter pupillae and the ciliaris muscle (Figure 19.11).

The ***dilator pupillae*** is supplied by sympathetic nerves. The preganglionic neurons concerned are located in the intermediolateral grey column of the first thoracic segment of the spinal cord. Their axons emerge through the anterior nerve root of the first thoracic nerve to reach the stellate ganglion. They, however, pass through this ganglion without relay and ascend in the sympathetic trunk to reach the superior cervical sympathetic ganglion.

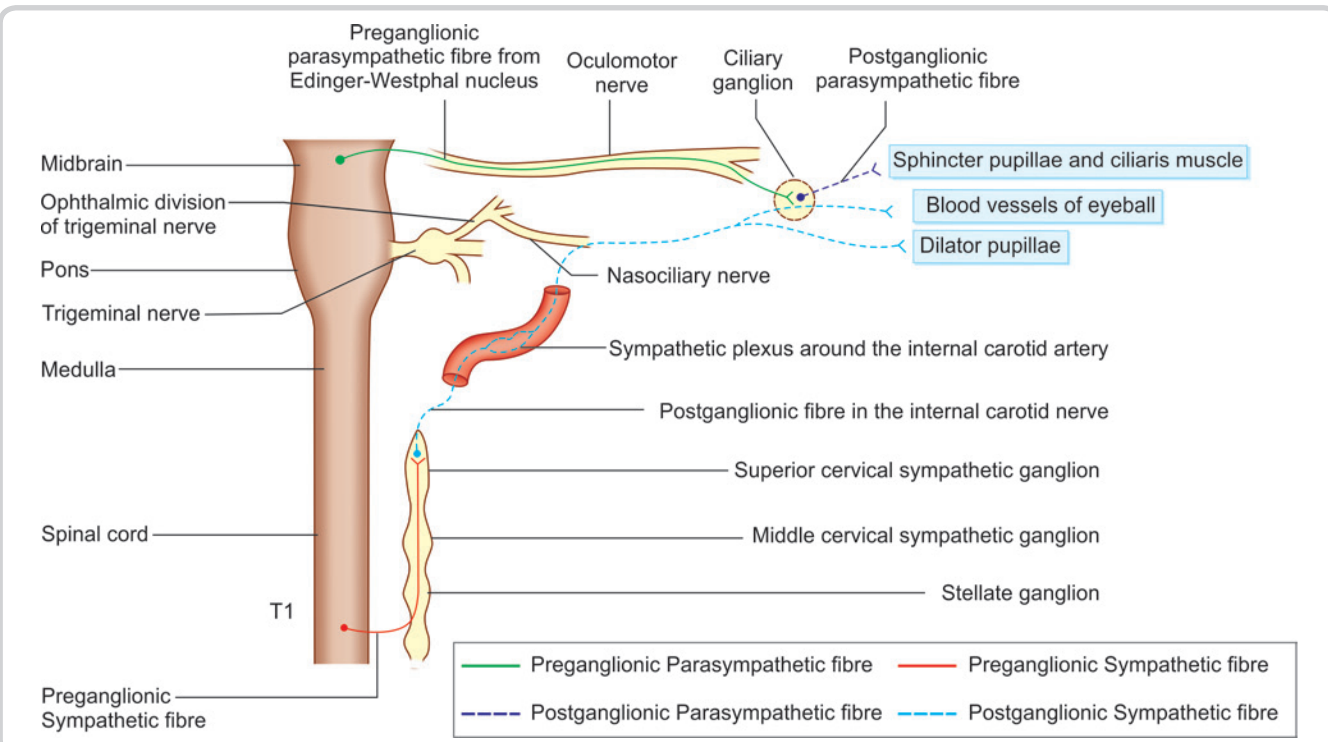

Figure 19.11: Scheme to show innervation of the pupil

Postganglionic neurons are located in this ganglion. Their axons pass through the internal carotid nerve. In the cavernous sinus, they pass (through communicating twigs) to the ophthalmic division of the trigeminal nerve. They travel through the nasociliary nerve and its long ciliary branches to the dilator pupillae.

Some sympathetic fibres reach the eyeball after passing through the ciliary ganglion. These fibres do not relay in this ganglion but merely pass through it. They supply the blood vessels of the eyeball. Apart from the dilator pupillae and blood vessels, sympathetic fibres also supply the orbitalis muscle, (Müller III), and superior and inferior tarsal muscles of the eyelid (Müller I and II, respectively)

Clinical Correlation

Horner's syndrome

Interruption of sympathetic supply to the head and neck results in Horner's syndrome. This consists of the following:

- Constriction of the pupil (***miosis***)
- Drooping of the upper eyelids (***ptosis***)
- Reduced prominence of the eyeball (***enophthalmos***)
- Absence of sweating on the face and neck (***anhidrosis***)
- Loss of ciliospinal reflex (pinching of nap of neck ***does not*** cause dilatation of pupils).

Salivary Glands

Submandibular and Sublingual glands

The secretomotor supply to the salivary glands is parasympathetic. Preganglionic neurons for the submandibular and the sublingual glands are located in the superior salivatory nucleus (Figure 19.12). Their axons pass through the facial nerve, its chorda tympani branch, and then through the lingual nerve, to reach the submandibular ganglion. The postganglionic neurons are located in this ganglion. Their axons reach the submandibular gland through branches from the ganglion to the gland. Some postganglionic neurons may be located in the hilum of the submandibular gland.

Fibres meant for the sublingual gland re-enter the lingual nerve and pass through its distal part to reach the gland.

Parotid Gland

The preganglionic neurons for the parotid gland are located in the inferior salivatory nucleus. Their axons pass through the glossopharyngeal nerve and its tympanic branch, the tympanic plexus, and the lesser petrossal nerve to terminate in the otic ganglion (Figure 19.13). Postganglionic fibres arising in this ganglion reach the gland through the auriculotemporal nerve.

Sympathetic fibres travel to salivary glands along the blood vessels which causes vasoconstriction and therefore produces a thick, viscous saliva.

Lacrimal Gland

Preganglionic neurons for the lacrimal gland are located in the lacrimatory nuclus near the superior salivary nuclei. Their axons pass through the facial nerve, its greater petrosal branch, and through the nerve of the pterygoid canal to reach the pterygopalatine ganglion (Figure 19.14). Postganglionic fibres arising in this ganglion pass successively through the maxillary nerve, its zygomatic branch, the zygomaticotemporal nerve, a communicating

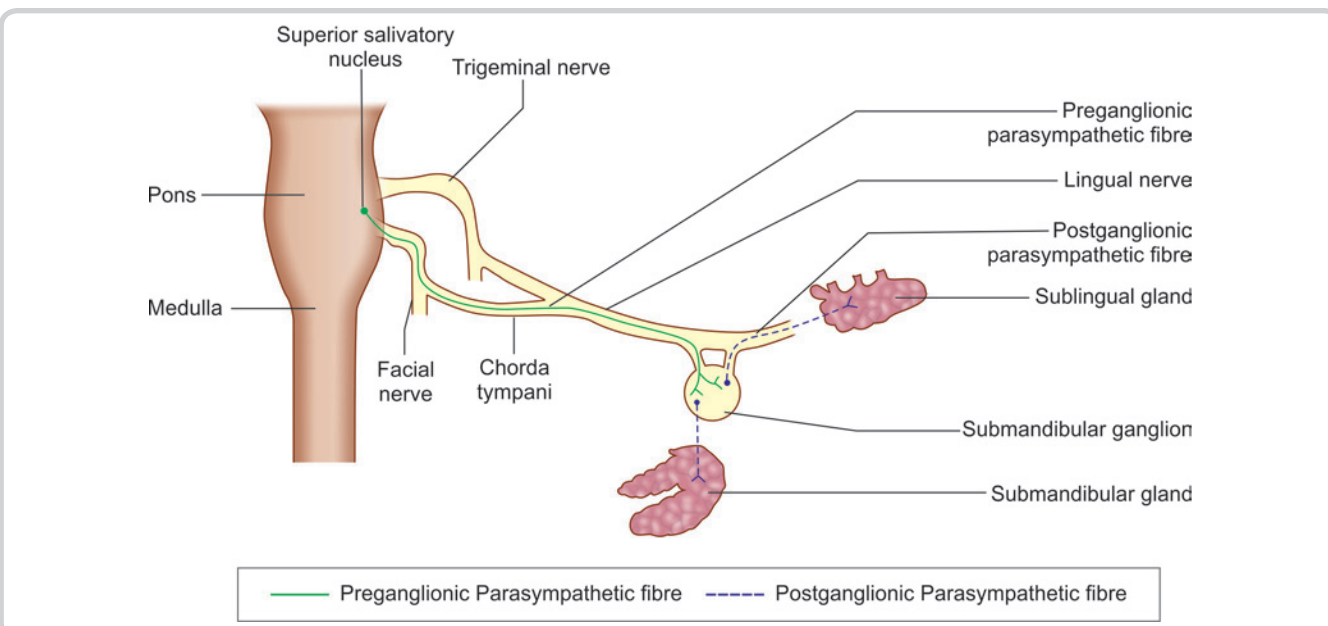

Figure 19.12: Scheme to show secretomotor pathway to submandibular and sublingual salivary glands

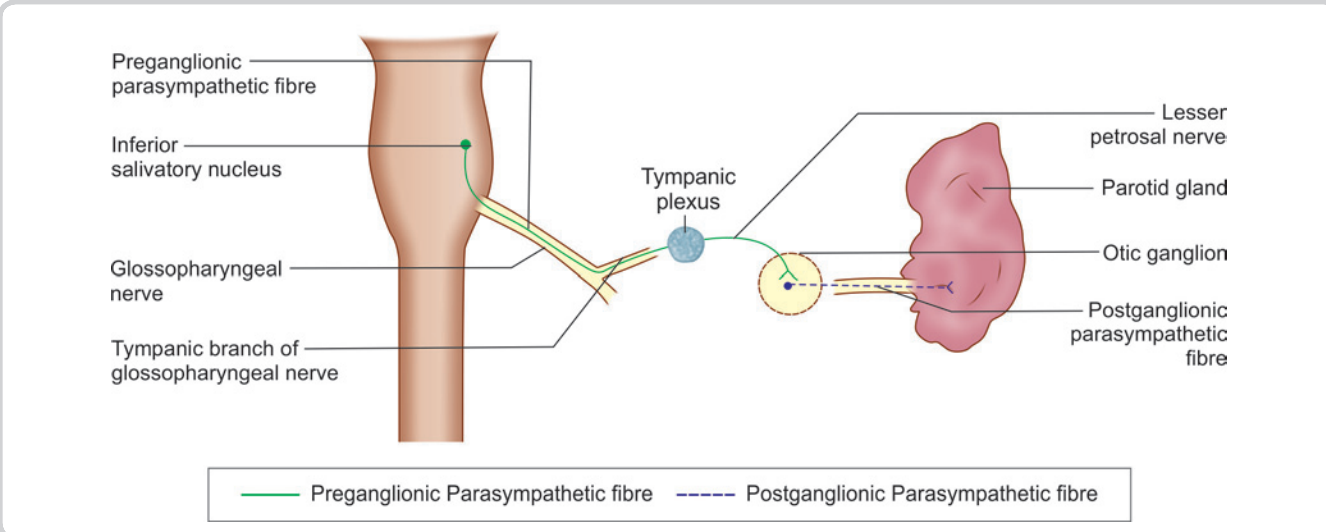

Figure 19.13: Scheme to show the scretomotor pathway for the parotid gland

branch from the zygomaticotemporal nerve to the lacrimal branch of the ophthalmic nerve, and finally, through the lacrimal branch itself to reach the gland.

Heart

Parasympathetic preganglionic neurons for the heart are located in the dorsal nucleus of the vagus. They reach the heart through cervical cardiac branches of the vagus. The postganglionic neurons are located within the superficial and deep cardiac plexuses. Their axons are distributed to the SA node, the atria, the AV node, and the AV bundle.

Preganglionic sympathetic neurons are located in segments T1 to T5 of the spinal cord (Figure 19.15). On reaching the sympathetic trunks their axons synapse with postganglionic neurons in the upper thoracic ganglia. Some fibres run upwards in the sympathetic trunk to end in cervical sympathetic ganglia. Postganglionic fibres leave these ganglia through their cardiac branches, and join the vagal fibres in forming the cardiac plexuses.

Contraction of cardiac muscle is not dependent on nerve supply. It can occur spontaneously. The nerves supplying the heart, however, influence heart rate. Sympathetic stimulation increases heart rate and parasympathetic stimulation reduces it. Sympathetic nerves supplying the coronary arteries cause vasodilatation increasing blood flow through them.

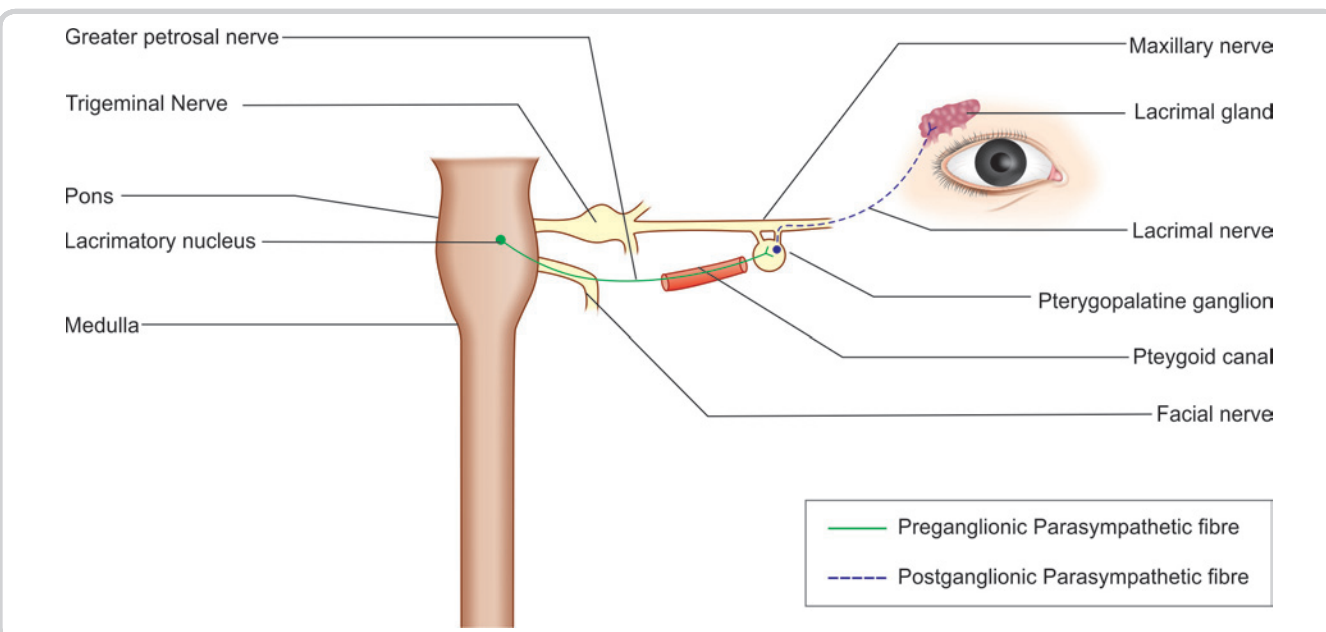

Figure 19.14: Scheme to show innervation of the lacrimal gland

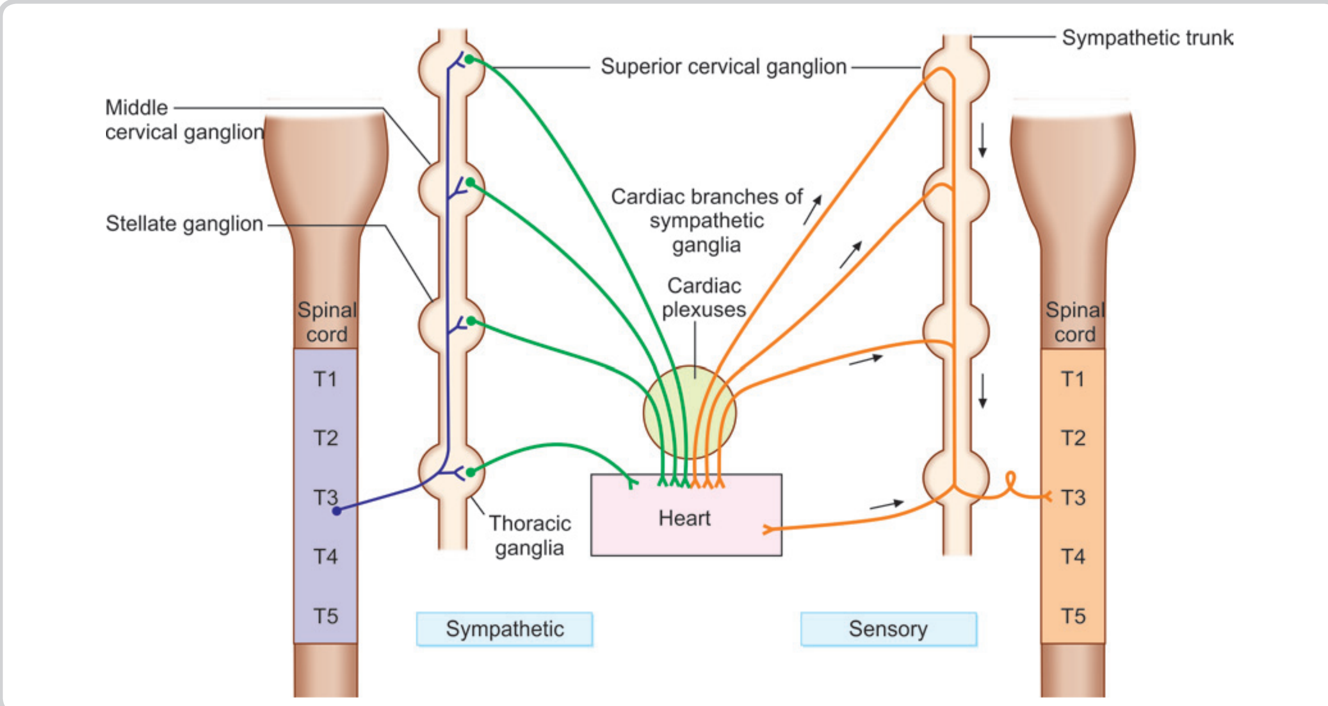

Figure 19.15: Scheme to show the sympathetic innervation of the heart – Afferent fibres travelling along the sympathetic nerves are also shown

Afferent fibres from the heart travel through both sympathetic and parasympathetic pathways. Afferent fibres running along the vagus are concerned with reflexes controlling the activity of the heart.

Clinical Correlation

Impulses of pain arising in the heart, due to ischaemia, are carried mainly by the sympathetic cardiac branches and enter the spinal cord through spinal nerves T1 to T5. These pathways are important as they convey impulses of pain produced as a result of anoxia of heart muscle (angina). The pain is predominantly retrosternal (T2 to T5, but it may be referred in various directions including the inner side of the left arm (T1).

Bronchi

Parasympathetic preganglionic neurons, that supply the bronchi, are located in the dorsal vagal nucleus. The fibres travel through the vagus and its branches, to reach the anterior and posterior pulmonary plexuses. Postganglionic neurons are located near the roots of the lungs. Their axons run along the bronchi and supply them.

Preganglionic sympathetic neurons are located in the second to fifth thoracic segments of the spinal cord. Their axons terminate in the corresponding sympathetic ganglia. Postganglionic fibres arising in these ganglia reach the bronchi through branches from the sympathetic trunks to the pulmonary plexuses.

Parasympathetic stimulation causes bronchoconstriction, while sympathetic stimulation causes bronchodilatation. Parasympathetic stimulation also has a secretomotor effect on glands in the bronchi. Sympathetic stimulation causes vasoconstriction.

Gastrointestinal Tract

- The parasympathetic nerve supply of the greater part of the gastrointestinal tract (from the pharynx to the junction of the right two thirds of the transverse colon with the left one third) is through the vagus. The preganglionic neurons are situated in the dorsal nucleus of the vagus.
- The hindgut is supplied by the sacral part of the parasympathetic system. The preganglionic neurons concerned are located in the second, third and fourth sacral segments of the spinal cord. They emerge through the ventral nerve roots of the corresponding nerves, and pass into their pelvic splanchnic branches. The fibres to the rectum and the upper part of the anal canal pass through the inferior hypogastric plexus. The remaining fibres pass through the superior hypogastric plexus and are distributed along the inferior mesenteric artery.
- The postganglionic parasympathetic neurons are located in the myenteric and submucosal plexus in the region to be supplied.
- Preganglionic sympathetic neurons for the gut are located in the thoracolumbar region of the spinal cord (Figure 19.16). Their axons pass through the sympathetic

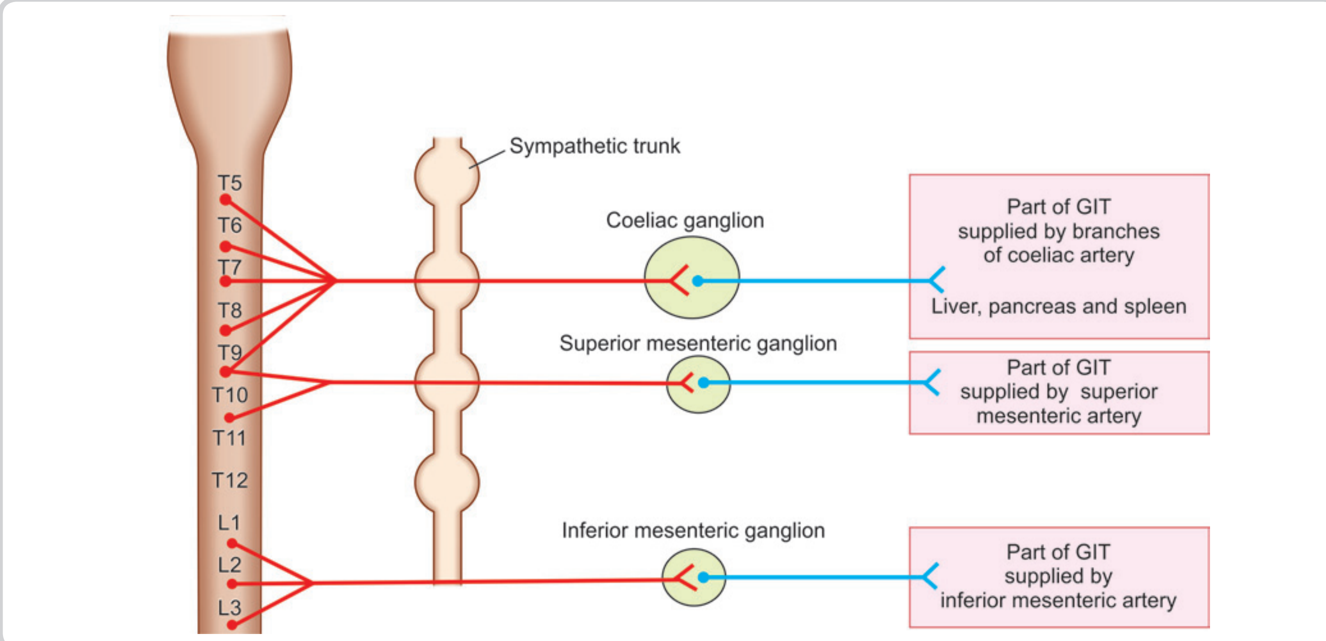

Figure 19.16: Scheme to show the sympathetic innervation of the gut

trunks without relay. They travel through the splanchnic nerves to terminate in plexuses (and ganglia) related to the coeliac artery, the superior mesenteric artery and the inferior mesenteric artery. Postganglionic neurons are located in these plexuses. They travel along these blood vessels to reach the gut.

Parasympathetic nerves stimulate intestinal movement and inhibit the sphincters. They are secretomotor to the mucosal glands. Sympathetic fibres are distributed chiefly to blood vessels.

Afferent fibres travel both along sympathetic and parasympathetic pathways. Pain from most of the gastrointestinal tract travels along sympathetic nerves. However, pain from the pharynx and oesophagus is carried by the vagus and that from the rectum and lower part of the pelvic colon by pelvic splanchnic nerves.

Urinary Bladder

The parasympathetic nerves to the urinary bladder are derived from the sacral outflow. The preganglionic fibres pass through the pelvic splanchnic nerves and the inferior hypogastric plexuses to reach the vesical plexus. Parasympathetic postganglionic neurons are located in the vesical plexus. Parasympathetic stimulation is motor to the detrusor muscle and inhibitory to the sphincter (Figure 19.17).

Sympathetic preganglionic neurons are located in spinal segments L 1, 2. Their axons terminate in the inferior mesenteric, superior hypogastric and inferior hypogastric plexuses. Postganglionic neurons are located in these plexuses. Sympathetic stimulation has an effect opposite to that of the parasympathetic.

Clinical Correlation

Sensory fibres carry impulses of distension and of pain from the urinary bladder. They run through both sympathetic and parasympathetic pathways. In the spinal cord, fibres carrying the two types of sensation follow different routes. Fibres carrying pain are located in the anterior and lateral white columns while fibres carrying the sensation of bladder filling travel through the posterior column. As a result, intractable bladder pain (such as may occur because of carcinoma) can be relieved by cutting the anterior and lateral white columns of both sides (bilateral anterolateral cordotomy) without abolishing the sensation of bladder filling.

The medial frontal cortex of both sides control the bladder centre in pons (pontine paramedian reticular formation). Lesions involving both medial frontal cortices (superior sagittal sinus thrombosis / meningioma of falx cerebri / occlusion of unpaired anterior cerebral artery) interrupt normal initiation of micturition (hesitancy), and stoppage of micturition when circumstances are unfavourable (urgency and precipitancy). This triad is called as ***uninhibited bladder***.

Severe lesions of the spinal cord above the sacral segments, involving the pontine reticulospinal tract, interfere with both afferent and efferent pathways. Normal micturition becomes impossible. However, the bladder empties reflexly when it is full (***automatic bladder***).

Lesion of sacral segments of spinal cord or the corresponding spinal nerves (conus-cauda syndrome) results in loss of spinal reflex for bladder emptying. Urinary bladder when it is filled beyond its capacity causes dribbling of urine called as overflow incontinence (***autonomous bladder***).

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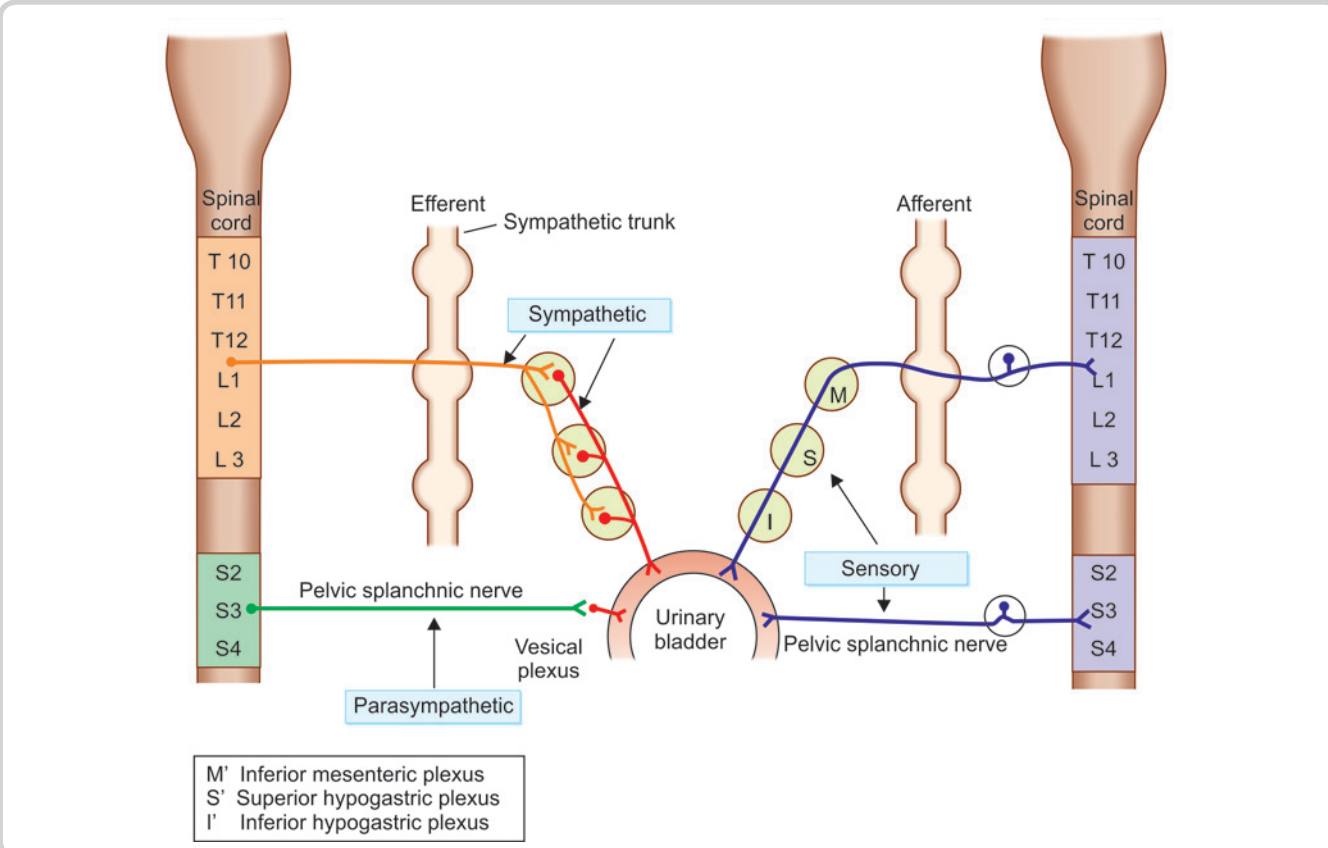

Figure 19.17: Scheme to show the innervation of the urinary bladder

Ureter

Autonomic nerves to the ureter are predominantly sensory in function. They are derived mainly from segments T12, L1 of the cord and also from segments S2 to S4. Distension by a stone causes severe pain (incorrectly called, renal colic). This is referred to a severe, radiating pain from loin (T12) to groin (L1).

Clinical Correlation

Raynaud's disease (or phenomenon)

In all persons, exposure to cold can cause vasoconstriction. In some persons, this response is abnormally high and vasoconstriction of arterioles in the distal part of the limb may seriously impair blood supply to the hands. In such cases, a series of events may be observed. When the hand is cooled first, there is a loss of colour (blanching) and the hand becomes pale. After an interval, the arterioles dilate and blood starts flowing into the hand, but this blood is deoxygenated (because of stagnation in arteries). The hand becomes swollen and dark. As more blood flows into the hand, the deoxygenated blood is washed off (with oxygenated blood) and the hand becomes red in colour.

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Basically, the condition is caused by abnormally active sympathetic nerves. It can be controlled with drugs. In more severe cases, sympathetic denervation of blood vessels of the limb is necessary. This can be achieved by surgical removal of the upper thoracic sympathetic ganglia (***preganglionic cervicodorsal sympathectomy***). Care has to be taken not to damage the stellate ganglion or the fibres entering or leaving it; else it would result in Horner's syndrome.

Thromboangiitis obliterans (Buerger's disease)

In this condition, arteries of the leg and foot are narrowed, and there is thrombophlebitis of veins. The condition is seen only in male smokers. Localized inflammatory changes are present in the walls of arteries and veins. Symptoms of arterial insufficiency are present. Gangrene of toes can occur. The condition can sometimes be controlled by complete abstinence from smoking and may benefit from lumbar sympathectomy which will result in vasodilation. Care has to be taken not to damage the first lumbar ganglion; else it would result in absence of ejaculation.

A comparison between sympathetic and parasympathetic nervous systems, and their effects on organs, have been summarized in Table 19.3 and Table 19.4, respectively.

Table 19.3 | Comparison between the sympathetic and parasympathetic nervous system

Components	Sympathetic system	Parasympathetic system
Highest modulators	Limbic region	Limbic region
Hypothalamus	Caudal	Rostral
Brain stem control	Reticular formation	Reticular formation
Supraspinal fibres	Hypothalamospinal fibres	Dorsal longitudinal fasciculus and hypothalamospinal fibres
Preganglionic neurons (connector neurons)	Intermediolateral grey column of T1 to L2	General visceral efferent nuclei and intermediolateral grey column of cranial nerves III, VII, IX, X and S2 to S4
Preganglionic fibres	Along with ventral nerve roots of thoracolumbar nerves	Along with cranial nerves III, VII, IX, X and ventral nerve roots of sacral nerves
Myelination of preganglionic fibres	Myelinated (white ramus communicans)	Myelinated
Length of preganglionic fibres	Relatively short	Relatively long
Preganglionic neuron terminal (and receptor) / Neurotransmitter	Acetylcholine (nicotinic receptor)	Acetylcholine (nicotinic receptor)
Ganglia of relay (Effector neuron)	Paravertebral and plexus along the abdominal aorta and internal iliac artery	Ciliary, pterygopalatine, submandibular, otic, cardiopulmonary plexus and in the wall of the viscera
Ratio of preganglionic fibres to neurons of ganglia	One is to many (therefore mass discharge)	One is to a few (therefore localised effect)
Postganglionic fibres	Along spinal nerves, blood vessels and visceral branches of paravertebral chain	Through branches of trigeminal in head region; and direct ganglionated branches
Myelination of postganglionic fibres	Unmyelinated	Unmyelinated
Length of postganglionic fibres	Relatively long	Relatively short
Postganglionic neuron terminal (and receptor) / Neurotransmitter	Noradrenaline (α and β adrenergic receptor) and Acetylcholine (muscarinic receptor to sweat gland and some blood vessels of skeletal muscle)	Acetylcholine (muscarinic receptor)
Effect	Response as in “fright-flight-fight” response	Responsible for homeostasis
Metabolism	Catabolic	Anabolic

Table 19.4 | Response of organs to sympathetic and parasympathetic nervous system

Organs	Sympathetic system	Parasympathetic system
Eye	Dilatation of pupils and contraction of orbitalis and smooth muscles of tarsals	Constriction of pupils and ciliaris muscle for accommodation
Lacrimal gland	–	Secretion
Salivary glands	Thick, viscous secretion	Profuse, watery secretion
Heart	Increases heart rate, increases contractility	Decreases heart rate, decreases contractility
Lung	Bronchial smooth muscle relaxation	Bronchial smooth muscle contraction
Gastrointestinal tract	Decreases motility, contraction of sphincters and inhibition of secretion	Increases motility, relaxation of sphincters and stimulation of secretion
Urinary bladder	Relaxation of detrusor and contraction of involuntary sphincter vesicae	Contraction of detrusor and relaxation of involuntary sphincter vesicae
Male sex organs	Ejaculation	Erection
Skin	Contraction of arrector pili and secretion of sweat glands	–
Blood vessels	Vasoconstriction, dilation in some vessels	–

Multiple Choice Questions

1. Which of the following exocrine glands gets secretomotor innervation from the sympathetic part of the autonomic nervous system?
A. Bronchial
B. Anal
C. Sweat
D. Bartholin's gland

2. The "stellate ganglion" is formed by the fusion of which of the following ganglia?
A. Middle and inferior cervical
B. Inferior cervical and first thoracic
C. First and second thoracic
D. Second and third thoracic

3. The usual number of pairs of thoracic ganglia is
A. 8
B. 9
C. 10
D. 11

4. The white rami communicantes contain fibres from
A. Paravertebral sympathetic ganglia to spinal nerves
B. Paravertebral sympathetic ganglia to viscera
C. Spinal cord to paravertebral sympathetic ganglia
D. Viscera to paravertebral sympathetic ganglia

5. The grey rami communicantes entering the spinal nerves function as
A. Vasomotor
B. Pilomotor
C. Sudomotor
D. All of the above

6. The internal carotid nerve is a branch of
A. Vagus
B. Glossopharyngeal
C. Superior cervical ganglion
D. Stellate ganglion

7. Which of the following autonomic nerve plexuses is situated near the bifurcation of the abdominal aorta?
A. Superior hypogastric
B. Inferior hypogastric
C. Superior mesenteric
D. Inferior mesenteric

8. The control of the parasympathetic part of the autonomic nervous system is which part of hypothalamus?
A. Caudal
B. Lateral
C. Medial
D. Rostral

9. Where are the cell bodies that convey painful impulses from the heart located?
A. Ganglia located in cardiac plexus
B. Upper thoracic dorsal root ganglia
C. Substantia gelatinosa of thoracic spinal cord
D. Upper thoracic sympathetic ganglia

10. The receptors of postganglionic autonomic nerve endings at sudoriferous glands are
A. Muscarinic
B. Nicotiinic
C. α adrenergic
D. β adrenergic

Answers

1. C **2.** B **3.** D **4.** C **5.** D **6.** C **7.** A **8.** D **9.** B **10.** A

Chapter 20

Imaging Techniques of Central Nervous System

Specific Learning Objectives

At the end of learning, the student shall be able to:
- Describe the various imaging modalities available for neurological disorders
- Describe the principles of internal carotid angiography, vertebral angiography, computerized tomography (CT), and magnetic resonance imaging (MRI)
- Identify important anatomical structures in angiography, CT and MRI scans
- Explain the advantages and disadvantages of CT scan and MRI

INTRODUCTION

Diagnosing a neurological disease involves a thorough history-taking and physical examination aided by an array of basic to sophisticated investigations so as to anatomically localize the lesion and also to know its pathology. The investigative techniques used in the diagnosis of neurological disorders vary from plain radiography of skull and vertebral column to complex MR tractography. Since nervous tissue is an excitable one and its main function is carried out by transmission of electrical impulse, electrophysiological studies like electroencephalography (EEG), electromyography (EMG), estimation of somatosensory evoked potentials, (EPs), nerve conduction studies etc. to assess the function of central nervous system (CNS) have been in vogue since a long time. With the advent of X-rays, plain radiography of skull or vertebral column in different positions has provided information about pathology lying within. Radiography of the skull after injection of air into the ventricular system (air ventriculography) or into the subarachnoid space (pneumoencephalography) has become obsolete with the arrival of CT scan. MRI further revolutionized the imaging modalities of CNS by providing not only structural information but also information about functional status.

So, there are some investigations that are carried out to assess the structure of the nervous system and there are some other investigations which assess the functions of the nervous system. Of the investigations to assess the anatomical structure of the nervous system, there are some which detect parenchymal abnormalities and others which detect vascular abnormalities (Figure 20.1).

Another method of classifying the neuroimaging modalities is based on the technique used (Figure 20.2).

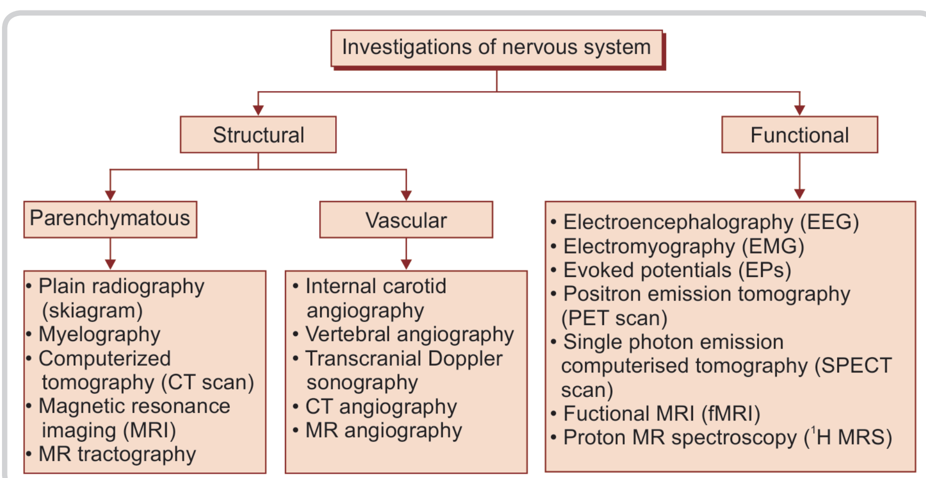

Figure 20.1: A flow chart showing different types of investigations used for neurological diagnosis

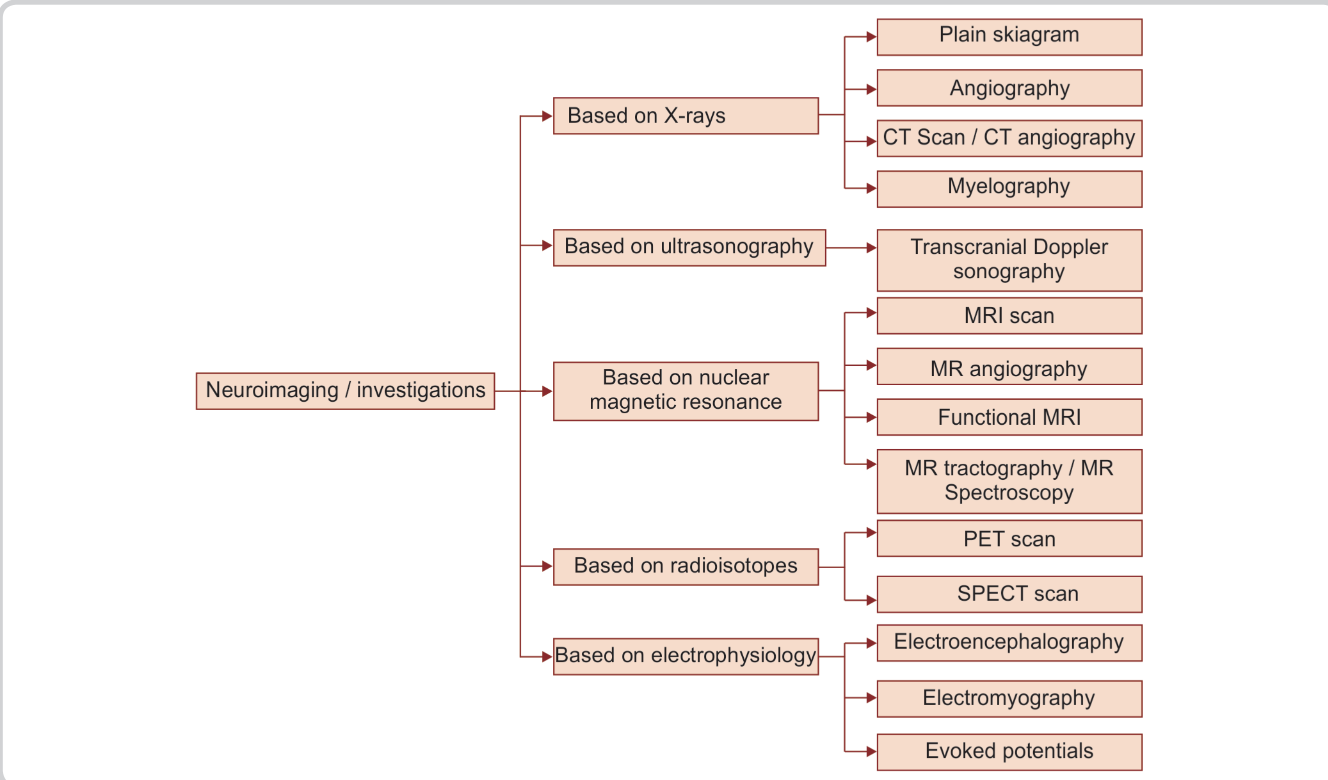

Figure 20.2: Classification of neuroimaging modalities based on techniques used

PLAIN SKIAGRAPHY / RADIOGRAPHY

Using X-rays, a posteroanterior and a lateral image of the skull are obtained. Sometimes specialized views like Towne's (Fronto-occipital projection) view and Waters' view (Occipito-mental projection) are used to study specific anatomical structures like base of skull and paranasal air sinuses respectively. The basic principle in plain radiography is that the X-rays incident on bone, soft tissue or fluid/air get absorbed to a different extent and the emergent beam after such absorption reacts differently with the chemical on the X-ray plate. So, bone produces a dense white shadow, air produces a black shadow and the soft tissue produces varying shades of grey. Abnormalities may be seen as:

- Thinning/erosion/fracture of the skull bones
- Widening of hypophyseal fossa
- Shift of the calcified pineal gland from midline

MYELOGRAPHY

In this investigation, a radio-opaque dye is injected into the spinal subarachnoid space after lumbar puncture. Using X-rays and by tilting the table on which the patient lies, the required part of spinal cord can be visualized as the dye surrounds the spinal cord and produces a radio-opaque shadow. Abnormality may be seen as a filling defect due to prolapsed intervertebral disc or tumors.

ANGIOGRAPHY

Injection of a radio-opaque dye into the blood vessels supplying the brain namely the internal carotid artery and the vertebral artery and taking serial radiographs of skull to show the ***arterial, the capillary and the venous phases*** of flow of the dye helps to visualize the normal anatomy of the arterial system, any block present or abnormalities like aneurysm or arterio-venous malformation (AVM). The anatomical route of access is usually through the femoral artery into which a catheter is passed and guided up to the arch of aorta. From there, the catheter is led into common carotid and then into internal carotid arteries and the dye is injected to get ***internal carotid angiogram (ICA)*** (Figure 20.3). If the catheter is pushed into the subclavian artery and then into the vertebral artery and the dye is injected, ***vertebral angiogram (VA)*** (Figure 20.4) is obtained.

In these radiograms, the image of the surrounding bones can be digitally subtracted to get a better visualization of the vessels. These are called as ***digital subtraction angiograms (DSAs)***.

COMPUTERIZED TOMOGRAPHIC SCAN (CT SCAN)

This technique uses a collimated beam of X-rays which is passed circumferentially around a transverse slice of head and multiple detectors around the slice capture the emerging X-rays to produce multiple images. These

Figure 20.3: Internal carotid angiogram (DSA)
(Courtesy: Dr. H. D. Deshmukh, Professor & Head, Department of Radiology, Seth GS Medical College & KEM Hospital, Mumbai)

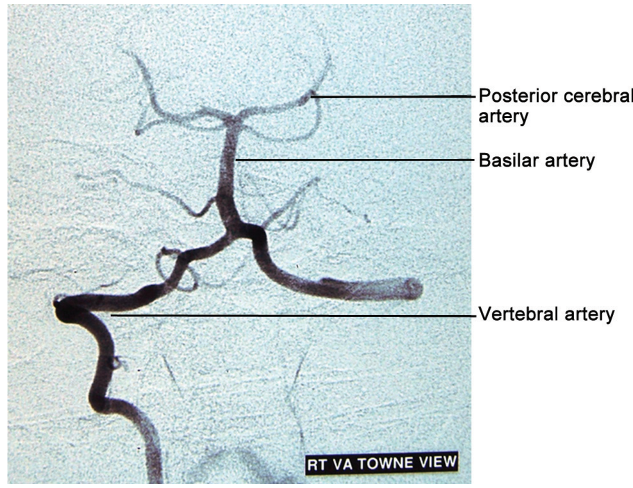

Figure 20.4: Vertebral angiogram (DSA)
(Courtesy: Dr. H. D. Deshmukh, Professor & Head, Department of Radiology, Seth GS Medical College & KEM Hospital, Mumbai)

are then put together with the help of a computer to get an axial tomogram. In this, just like in plain radiography, the bone produces a white shadow, the cerebrospinal fluid (CSF) produces a black shadow and neural tissue is seen in varying shades of grey (Figures 20.5A and B). Abnormalities are seen as:

- Shift of falx cerebri from midline
- Hyperdense or hypodense shadows to show hemorrhage, infarct etc
- Dilatation of ventricular cavity as in hydrocephalus (Figure 20.6)

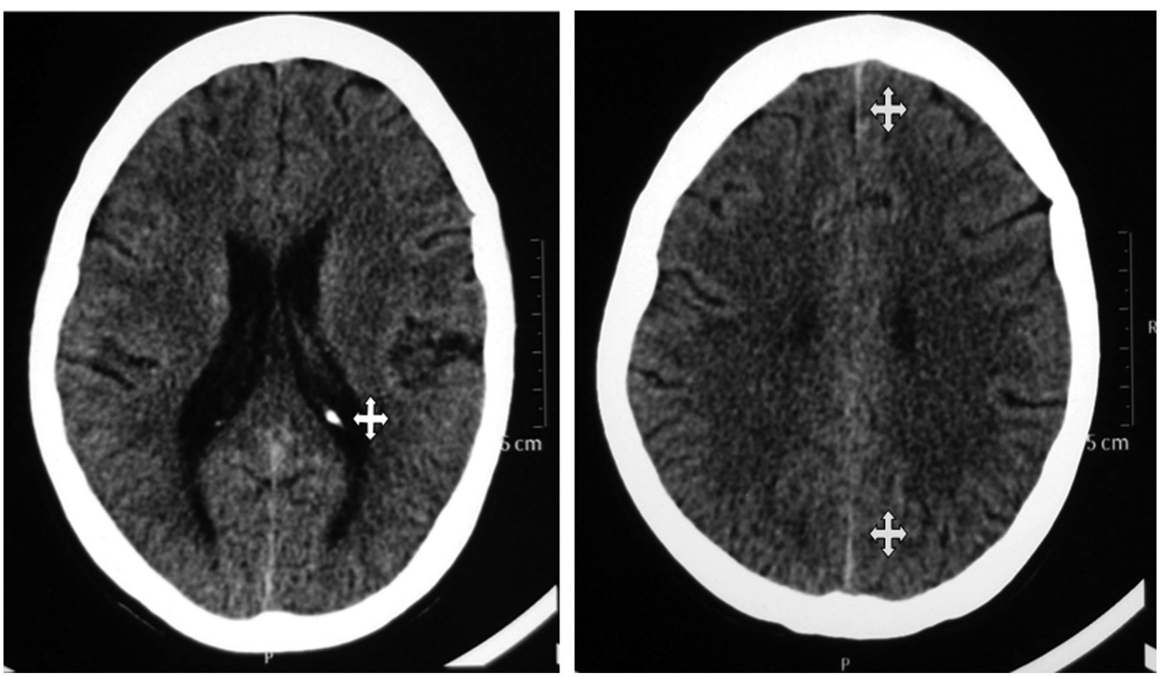

Figure 20.5A and B: (**A**) CT scan image showing CSF as black shadow within lateral ventricle–Red coloured quad arrow shows a white spec within the ventricle- choroid plexus in the collateral trigone. (**B**) CT scan image showing falx cerebri as a thin white line in the midline-yellow quad arrow- Sulci and gyri can be appreciated in the periphery
(Courtesy: Dr. H. D. Deshmukh, Professor & Head, Department of Radiology, Seth GS Medical College & KEM Hospital, Mumbai)

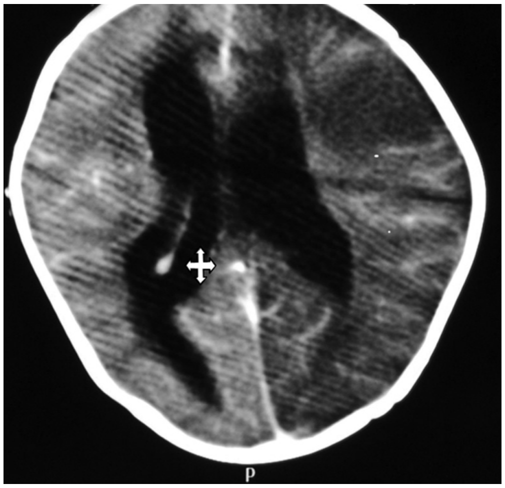

Figure 20.6: CT scan image showing CSF as black shadow within dilated ventricle of a small child with hydrocephalus—red quad arrow denotes choroid plexus within the ventricle
(Courtesy: Dr. H. D. Deshmukh, Professor & Head, Department of Radiology, Seth GS Medical College & KEM Hospital, Mumbai)

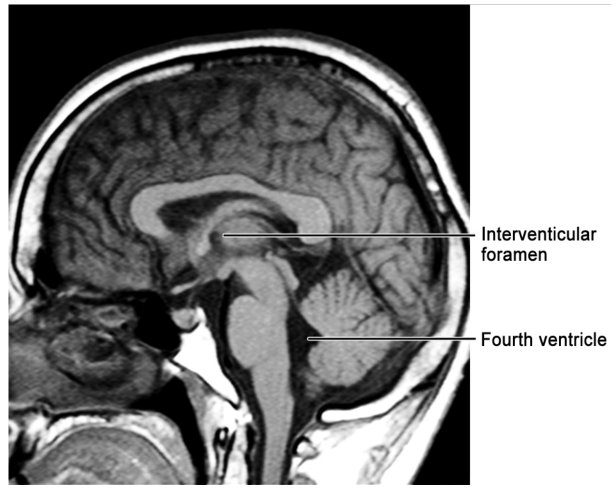

Figure 20.7: MRI showing sagittal view of the brain
(Courtesy: Dr. H. D. Deshmukh, Professor & Head, Department of Radiology, Seth GS Medical College & KEM Hospital, Mumbai)

MAGNETIC RESONANCE IMAGING (MRI)

This investigation uses the principle of nuclear magnetic resonance which states that the atoms of a tissue/ substance oscillate and release energy when subjected to a strong magnetic field. This energy is captured in the form of an image (T1 weighted image). Later when the oscillating atoms are subjected to radiofrequency waves, the direction of oscillation changes and releases energy in another direction and a diametrically opposite image is produced (T2 weighted image). In T1 weighted image, the nervous tissue appears brighter / whiter and fluid like CSF appears darker. In T2 weighted image, the CSF appears brighter in contrast to nervous tissue which appears darker. The image of the brain can be obtained in sagittal (Figure 20.7), coronal (Figure 20.8) and axial views.

Abnormalities are visualized as:

- Bright or dark images of tumours depending on whether it is T1 weighted or T2 weighted sequence
- Dilated ventricles of hydrocephalus seen as bright shadow in T2 weighted images

Comparison between CT and MRI has been made in Table 20.1.

CT ANGIOGRAPHY

In this investigation, a radio-opaque contrast medium is injected into the peripheral vein and then CT scans of the head region are obtained to study the blood vessels of brain. Using multi slice detector (MDCT), 3-D reconstruction of the vessels can be obtained. Compared to catheter angiography, this method is less invasive. Abnormalities like stenosis of vessels, aneurysmal dilatation, anteriovenous (AV) malformation, etc can be made out.

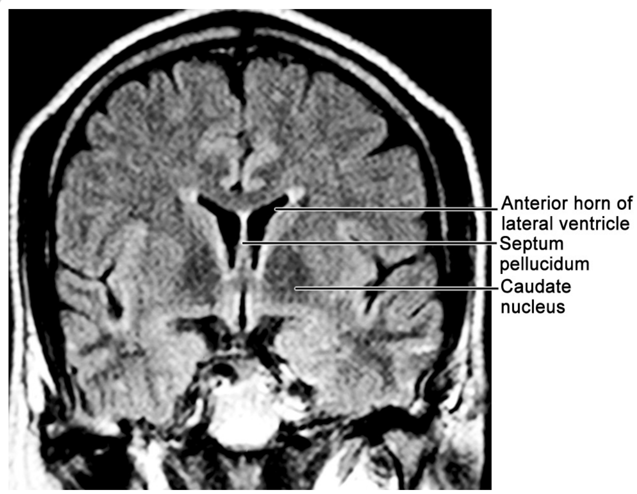

Figure 20.8: MRI showing coronal view of the brain
(Courtesy: Dr. H. D. Deshmukh, Professor & Head, Department of Radiology, Seth GS Medical College & KEM Hospital, Mumbai)

MR ANGIOGRAPHY

During MRI, a special contrast material, e.g. gadolinium compound, can be injected into the vessels. This enhancement with contrast gives better information about distribution of vessels. This procedure may not be as informative as catheter angiography.

TRANSCRANIAL DOPPLER SONOGRAPHY

This is based on Doppler effect in which the frequency of the ultrasound waves gets changed when they strike a moving object like the blood flowing in a vessel. The image produced shows any abnormality in the vessel as well as alteration of blood flow.

Table 20.1 | Comparison Between CT and MRI

Feature	CT	MRI
Mechanism	X-rays are used as a collimated beam circumferentially around a slice of head and images are taken	A circular magnet surrounds the head creating a magnetic field which is subjected to radiofrequency waves and images are taken
Resolution	Sectional images are of 2 mm resolution	Sectional images are of 0.5–1 mm resolution
Sections	Only transverse or axial sections	Axial, sagittal and coronal sections possible
Contrast	Neural tissue, fluid contrast obtained to a certain extent in the same image	Different types of imaging—T1 or T2 weighted to obtain better contrast for neural tissue including grey and white matter separation and CSF visualization
Time taken	Less	More; images are spoiled by movement of body part
Cost	Less expensive	More expensive
Side effects	Harmful because of exposure to X-rays	Not harmful as only magnetic field and radiofrequency waves are used
Restriction	Anyone can be subjected to CT scan	Patients with metallic implants in teeth, limbs or with pacemakers cannot undergo MRI

Abbreviations: CT, computerized tomography; MRI, magnetic resonance imaging; CSF, cerebrospinal fluid

POSITRON EMISSION TOMOGRAPHIC (PET) SCAN

Positron emitting radioisotopes like ^{15}O and ^{18}F are used in this study. When the positron emitted by these isotopes is met by an electron, the impact produces 2 gamma-ray photons which are detected and thus the area concentrating the isotope is identified.

Water containing ^{15}O will be picked up by blood and ^{18}F containing fluorodeoxyglucose will be picked up by the neurons as neurons have an affinity for glucose. When brain tissue is scanned after administration of these isotope containing substances, high metabolic areas with more blood flow or neurons with higher glucose intake will show up as hot spots. The advantage over CT is PET gives information about function because of neuronal activity or blood flow. Though the resolution obtained is (5–10 mm) better than SPECT, this method is inferior to CT or MRI. The other limitation would be PET scans can be set up only in hospitals which have facility for synthesizing radioactive chemicals (cyclotron).

SINGLE PHOTON EMISSION COMPUTERIZED TOMOGRAPHIC (SPECT) SCAN

Ordinary gamma-emitting isotope emits a single photon on disintegration. When neuronal tissues take up such radioisotopes, the single photons that are emitted by the isotope are picked up by blood stream. Depending on the blood flow, the clearance of photons will vary and that will produce differing images on scan. The resolution is quite low (2–3 cm) as compared to other imaging techniques, but it is less expensive and the time needed is also less.

FUNCTIONAL MRI (fMRI)

This imaging technique is based on the principle of activation of neurons. Wherever, the neurons are active, there is an increase in blood volume, an increase in blood flow velocity and an increase in the blood oxygenation levels. This technique is blood oxygenation level dependent (BOLD) and uses the magnetic properties of deoxyhemoglobin to measure the MR signals in T2 weighted sequence when a specific task is being performed.

Two new techniques related to this fMRI are arterial spin labelling (ASL) and functional diffusion MRI (fdiffusion MRI) which provide better temporal and spatial resolution. But these are yet under research and may soon be available for patients. fMRI provides clinicoanatomical information in patients with Alzheimer's disease or Parkinsonism and is also to assess structural and functional alterations in some psychiatric conditions.

PROTON MAGNETIC RESONANCE SPECTROSCOPY (^{1}H MRS)

This is a non-invasive investigation to assess the presence and concentration of certain metabolites like creatinine, choline, aspartate, etc and neurotransmitters like gamma-aminobutyric acid (GABA) by picking up their oscillation signals with the help of MRI. It helps to assess the metabolic activity in a tumour and also the behaviour of nervous tissue after a cerebral infarct. At present, this is used more for research but future applications will be for assessment of the penumbra of an ischemic stroke, epilepsy, cerebral tumours, multiple sclerosis and some psychiatric conditions like depression.

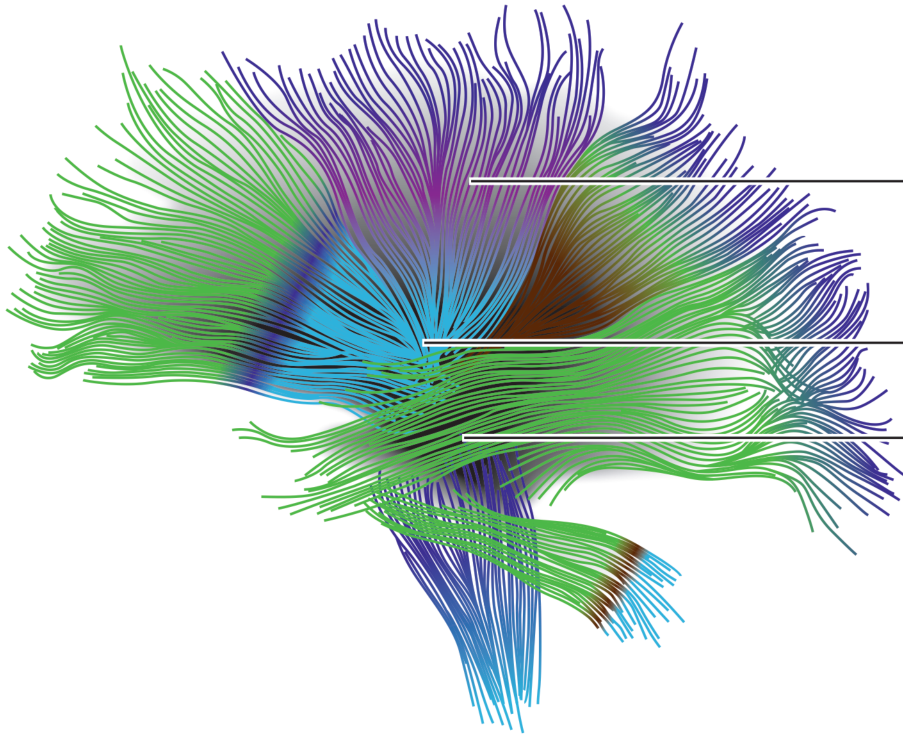

Figure 20.9: MR Tractography showing white matter of cerebrum

MR TRACTOGRAPHY

This imaging technique is based on the principle of diffusion weighted imaging (DWI). It is believed that the water molecules in live tissues are in constant motion due to the thermal energy carried by them and this is called as ***Brownian motion***. In white matter of the brain, this motion is along the longitudinal axis of the white fibres because the axolemma limits their perpendicular motion. MR signals catch these motions and different computer algorithms are used to reconstruct the fibre tracts called as ***diffusion tensor imaging (DTI)*** or MR Tractography (Figure 20.9).

This imaging modality has very fascinating applications as it can non-invasively visualize anatomical connections between various parts of CNS and can offer very useful inputs in the diagnosis and management of acute stroke, tumours, schizophrenia, etc.

Glossary

Greek / Latin term	English meaning
Abducens	Lead away
Abulia	Without willpower
Accumbens	Reclining
Acetylcholine	Vinegar bile
Acoustic	To hear
Adenohypophysis	Gland hypophysis (q.v.)
Adrenalin	Near the kidney
Afferent	To carry towards
Aganglionic	Without ganglion
Ageusia	Without taste
Agnosia	Without knowledge
Agraphia	Without ability to write
Akinesia	Without movement
Ala	Wing
Alexia	Inability to read
Allocortex	Other cortex (q.v.)
Allodynia	Other pain
Alveus	Canal, trough
Amacrine	Without long fibre
Ambiens	Both
Ambiguus	Doubtful
Ammonis	Egyptian deity with ram's head
Amnesia	Without remembrance
Ampulla	Small bottle
Amygdala	Almond
Amygdaloid	Almond-like
Anaesthesia	Without sensation
Analgesia	Without pain
Anastomotic	Communication between
Anencephaly	Without encephalon (q.v.)
Aneurysm	Widening

Greek / Latin term	English meaning
Angiogram	Vessel writing
Angular	Bend
Ansa	Looped handle
Antidromic	Against race course
Aphasia	Without speech
Apraxia	Without able to do
Aprosodia	Without song sung to rhythm
Aqueduct	Water canal
Arachnoid	Spider web-like
Arbor	Tree
Archicerebellum	Ancient cerebellum (q.v.)
Arcuate	Bow shaped
Astigmatism	Without point
Astrocyte	Star-like cell
Asynergia	Without coordination
Ataxia	Without orderliness
Athetosis	Without fixed position
Atrium	Main room
Atrophy	Without nourishment
Auditory	To hear
Autonomic	Self governed
Axolemma	Plasma membrane of axon (q.v.)
Axon	Axis
Axoplasm	Cytoplasm of axon (q.v.)
Basilar	Base
Bifida	Split
Bipolar	Two poles
Brachium	Arm
Bradykinesia	Slow movement
Bulb	Oval shaped

Greek / Latin term	English meaning
Calamus	Reed/stalk
Calcar	Spur
Calcarine	Spur-shaped
Callosum	Hard/tough
Capsule	Small box
Carotid	To put to sleep
Cauda	Tail
Caudate	Tail
Cavernous	Being in a large hollow space
Cephalic	Head
Cerebellum	Small brain
Cerebrum	Brain
Cervical	Neck
Chemoreceptor	Receive chemical
Chiasma	Cross
Chorea	Dance
Choroid	Like a membrane
Chromatolysis	Breakdown of colour
Ciliary	Eyelash
Cinereum	Ash grey
Cingulate	Belt
Cingulum	Belt
Circulus	Circle
Cistern	Reservoir or container
Clasp-knife	Foldable pocket knife
Claustrum	Barrier
Cleft	Space made by split
Cochlea	Snail shell
Coeliac	Belly
Coeruleus	Blue
Cogwheel	Toothed wheel
Collateral	Together by the side
Colliculus	Small hill
Coma	Deep sleep
Commissure	Joining together
Conjugate	Together yoke (neck)
Conjunctivum	Join
Connexus	Connection
Contra-coup	Opposite blow
Contralateral	Opposite side
Conus	Cone
Corneal	Horny tissue

Greek / Latin term	English meaning
Cornu	Horn
Corona	Crown
Corpus	Body
Corpuscle	Small corpus (q.v.)
Cortex	Outer layer (bark)
Cranial	Head
Crus	Leg
Culmen	Summit
Cuneus	Wedge
Cutaneous	Skin
Decussation	Crossing
Declive	Sloping downward
Dendrites	Tree
Dentate	Having teeth
Denticulate	Having small teeth
Diabetes	To pass through
Diencephalon	In between (dia) encephalon (q.v.)
Diplopia	Double vision
Dura	Hard
Dysarthria	Difficulty in articulation (speech)
Dysdiadochokinesisa	Difficulty in succeeding movement
Dyskinesia	Difficulty in movement
Dysmetria	Difficulty in measurement
Efferent	Carry away
Emboliform	Plug-like
Encephalogram	Encephalon (q.v.) writing
Encephalon	Organ inside the head (brain)
Enophthalmos	Inside eyeball
Enteric	Intestine
Entorhinal	Inside nose
Ependyma	Upper garment
Epithalamus	Above thalamus
Equina	Horse
Exteroceptor	External receiver
Extrafusal	Outside spindle
Facial	Face

Greek / Latin term	English meaning
Falx	Sickle
Fasciculus	Small bundle
Fasciolaris	Flat worm
Fastigial	Top of a gabled roof
Filum	Thread
Fimbria	Fringe
Fissure	Cleft or slit
Flaccid	Lacking firmness
Folium	Leaf
Forceps	Tongs/pincers
Fornix	Arch
Fossa	Trench/channel
Fovea	Pit/depression
Fundus	Bottom
Funiculus	Little cord
Fusiform	Spindle-shaped
Ganglion	Knot/swelling
Gelatinosa	Jelly
Gemmule	Small bud
Geniculate	Bent like a knee
Genu	Knee
Gliosis	Glue
Globose	Ball
Globus	Ball
Glomeruli	Small ball of thread
Glossopharyngeal	Tongue and throat
Gracile	Slender
Granule	Small grain
Gravis	Severe
Griseum	Grey
Gustatory	Taste
Gyrus	Ring, circle
Habenula	Rein
Haematoma	Swelling of blood
Haemorrhage	To burst forth with blood
Hemianopia	Half loss of vision
Hemiballisms	Half jumping
Hemiplegia	Half strike/blow
Hemisphere	Half sphere
Herpes	To creep
Hippocampus	Sea horse

Greek / Latin term	English meaning
Hydrocephalus	Water in the head
Hyperacusis	Loud hearing
Hypertrophy	Excess nourishment
Hypoglossal	Under the tongue
Hypophysis	Down growth
Hypothalamus	Under thalamus (q.v.)
Hypotonia	Decreased hold/grasp
Indusium	To put on/adorn
Infundibulum	Funnel
Insipidus	Tasteless
Insula	Island
Interoceptor	Between receiver
Interpeduncular	In between peduncle (q.v.)
Intersegmental	In between segments
Interstitial	In between placed
Interthalamic	In between thalamus (q.v.)
Intracerebellar	Inside cerebellum (q.v.)
Intrafusal	Within spindle
Intrinsic	Interior
Ipsilateral	Same side
Ischaemic	Stop blood
Isocortex	Equal cortex (q.v.)
Juxta-restiform	Next to restiform (q.v.)
Kernicterus	Yellowish-green nut
Laminae	Layer/thin plate
Leptomeninges	Slender meninges (q.v.)
Lemniscus	Woolen band or filet (ribbon)
Lenticularis	Shaped like a lens
Lentiform	Like a lens
Ligamentum	To bind
Limbic	Border/hem/fringe
Limen	Threshold
Limitans	To limit
Lingula	Little tongue
Locus	Location
Lumbar	Loin
Lunate	Moon
Lutea	Yellow
Macula	Spot, stain
Magna	Large
Mammilla	Small breast
Mater	Mother

Greek / Latin term	English meaning
Medulla	Innermost, marrow
Megacolon	Enlarged large intestine
Melatonin	Black serotonin (q.v.)
Meninges	Membranes
Meningocoele	Hernia of meninges (q.v.)
Meningo-encephalocoele	Hernia of meninges (q.v.) and encephalon (q.v.)
Meniscus	Crescent, moon
Mesencephalon	Middle encephalon (q.v.)
Metathalamus	After thalamus (q.v.)
Metencephalon	After encephalon (q.v.)
Microglia	Small glue
Mitral	Bishop’s turban
Monoplegia	One strike/blow
Multipolar	Many poles
Myasthenia	Muscle lack of strength
Myelencephalon	Marrow encephalon (q.v.)
Myelin	Marrow
Myelon	Organ within (the vertebrae) – spinal cord
Myopia	To shut eye
Neocerebellum	New cerebellum (q.v.)
Neocortex	New cortex (q.v.)
Neostriatum	New striatum (q.v.)
Neuralgia	Neuron (q.v.) pain
Neurites	Branch of neuron (q.v.)
Neurobiotaxis	Neuron (q.v.) life law
Neuroglia	Nerve glue
Neurohypophysis	Neuron (q.v.) hypophysis (q.v.)
Neurolemma	Neuron (q.v.) husk
Neuron	Nerve
Neuropil	Neuron (q.v.) felt
Neurotransmitter	Neuron (q.v.) send accross
Nigra	Black
Node	Knot
Nodule	Small node (q.v.)
Nucleus	Small nut
Nystagmus	Nodding, drowsiness
Obex	Barrier
Oblongata	Rather long
Oculomotor	Eye movement
Olfactory	To smell
Oligodendrocytes	Few tree cell

Greek / Latin term	English meaning
Operculum	Cover, lid
Ophthalmic	Eyeball
Optic	For sight
Otic	Ear
Oxytocin	Sharp birth
Pachymeninx	Thick membrane
Paleocerebellum	Old cerebellum (q.v.)
Paleocortex	Old cortex (q.v.)
Paleostriatum	Old striatum (q.v.)
Pallidus	Pale
Pallium	Cloak
Parahippocampal	Beside, beyond hippocampus (q.v.)
Paralysis	To loosen
Paraplegia	Beside, beyond blow or stroke
Parastriate	Beside, beyond striate (q.v.)
Parasympathetic	Beside, beyond consoling, comforting
Paraterminal	Beside, beyond end
Parolfactory	Beside, beyond olfactory (q.v.)
Peduncle	Stem-like
Pellucidum	Translucent
Peristriate	Around striate (q.v.)
Pes	Foot
Petrosal	Stony hard
Pia	Soft
Pineal	Pine cone
Piriform	Pear-shaped
Pituitary	Slime, mucous
Plexus	A braid
Poliomyelitis	Inflammation of Grey matter of spinal cord
Pons	Bridge
Positron	Positive electron.
Pretectal	Before tectum (q.v.)
Proprius	One’s own
Proprioceptor	Receiver
Prosencephalon	Before encephalon (q.v.)
Prosopagnosia	Inability to recognize faces
Ptosis	Fall
Pulvinar	Cushion, pillow, couch
Pupil	Doll, little girl
Putamen	Shell

Greek / Latin term	English meaning
Pyramis	Pyramid
Quadrigemina	Four twins
Quadriplegia	Four blow or stroke
Rachischisis	Main axis split
Radicularis	Small root
Ramus	Branch
Raphe	Seam
Receptor	Receiver
Reciprocal	Done in return
Rectus	Straight
Restiform	Rope-like
Reticular	Net-like
Retina	Net
Rhinal	Nose
Rhinencephalon	Nose encephalon (q.v.)
Rhombencephalon	Rhonbus encephalon (q.v.)
Rhomboid	Rhombus-like
Rigidity	Being stiff
Rostrum	Beak
Rubro	Red
Satellite	Attendant
Sclerosis	Hard
Scriptorius	Writing
Separans	Separating
Septal	Partition
Serotonin	Tonic inside serum
Siphon	Pipe, tube for drawing off fluid
Solitary	Alone
Somatotopic	Body place
Spastic	Drawing, pulling, stretching
Splenium	Bandage
Squint	Eyes askew
Stellate	Star
Strabismus	Eyes askew
Stria	Striped
Striate	Striped
Striatum	Striped
Subiculum	Small layer

Greek / Latin term	English meaning
Substantia	Substance
Subthalamus	Below thalamus (q.v.)
Sympathetic	Consoling, comforting
Synapse	Junction
Syndrome	The act of running together
Syringomyelia	Pipe / tube marrow (spinal cord)
Tabes	Emaciation
Tactile	Touch
Tanycyte	Stretched cell
Tapetum	Carpet
Tectum	Roof
Tegmental	Covering
Telencephalon	End encephalon (q.v.)
Tetanus	Muscle spasm
Thalamus	Inner chamber
Trabecula	Trabecula
Trapezoid	Trapezium-like
Tremor	Shake
Trigeminal	Triplet
Trigone	Three angles
Trochlear	Pulley
Tuber	Swelling
Tubercle	Small swelling
Uncus	Hook
Unipolar	One pole
Uvula	Little grape
Vagus	Wandering
Vallecula	Small valley
Vasocorona	Crowning vessel
Vasopressin	Vessel pressure
Velum	Covering
Ventricle	Small belly
Vermis	Worm
Vesicles	Blister, bladder
Vestibular	Entrance court
Vitae	Of life
Zona incerta	Belt uncertain
Zoster	Belt or girdle

NOTE: *q.v. = quod vide = which refer to*

Eponyms

Name of the scientist / discoverer	Nationality	Anatomical structure named after
Adamkiewicz, Albert	Polish Pathologist	Artery supplying lumbar segments of spinal cord
Alzheimer, Alois	German Neuropsychiatrist	Presenile and senile dementia
Argyll Robertson	Scottish Ophthalmologist	Pupillary constriction in accommodation, but not in response to light
Arnold, Julius	German Pathologist	Arnold-Chiari malformation
Auerbach, Leopold	German Anatomist	Myenteric plexus in the gastrointestinal tract
Babinski, Joseph François Félix	French Clinical Neurologist	Up-turning of the great toe and spreading of the toes on stroking the sole
Baillarger, Jules Gabriel François	French Psychiatrist	Bands of Baillarger in the cerebral cortex
Bell, Sir Charles	Scottish Anatomist, Clinical Neurologist, and Surgeon	Bell’s palsy (facial paralysis) and Bell-Magendie law (dorsal roots are sensory, ventral roots are motor)
Benedikt, Moritz	Viennese Neurologist	Oculomotor nerve palsy and ataxia including tremors
Betz, Vladimir A	Russian Anatomist	Giant pyramidal cells in the motor cortex
Broca, Pierre Paul	French Pathologist and Anthropologist	Motor speech area; and diagonal band of Broca in the anterior perforated substance
Brodmann, Korbinian	German Neuropsychiatrist	Brodmann’s area of the cerebral cortex
Brown-Séquard, Charles Edouard	Physiologist and Clinical Neurologist	Sensory and motor abnormalities in hemisection of the spinal cord
Bucy, Paul Clancy	American Neurosurgeon	Klüver-Bucy syndrome is caused by extensive bilateral lesions of the temporal lobes
Buerger, Leo	American Physician and Urologist	Chronic inflammatory disease of the peripheral vessels
Burdach, Karl Friedrich	German Physiologist	Fasciculus cuneatus (tract of Burdach)
Cajal, Santiago Felipe Ramón y	Spanish Histologist	Interstitial nucleus of midbrain; Neuron Doctrine on the basis of his observations with silver staining methods
Charcot, Jean-Martin	French Neurologist	Lenticulostriate branch of the middle cerebral artery
Chiari, Hans	Czech Physician	Arnold-Chiari malformation
Clarke, Jacob Augustus Lockhard	English Anatomist and Clinical Neurologist	Nucleus dorsalis (thoracicus) of the spinal cord
Corti, Marchese Alfonso	Italian Histologist	Sensory epithelium of the cochlea (organ of Corti)
Darkschewitsch, Liverij Osipovich	Russian Clinical Neurologist	One of the accessory oculomotor nuclei in the midbrain
Deiters, Otto Friedrich Karl	German Anatomist	Lateral vestibular nucleus,
Dejerine, Joseph Jules	French Neurologist	Hypoglossal alternating hemiplegia
Edinger, Ludwig	German Neuroanatomist and Clinical Neurologist	Edinger-Westphal nucleus is the parasympathetic component of the oculomotor nucleus

Name of the scientist / discoverer	Nationality	Anatomical structure named after
Fleischer, Bruno	German Ophthalmologist	Kayser-Fleischer ring in Wilson's disease
Forel, Auguste Henri	Swiss Neuropsychiatrist	Fibre bundles in the subthalamus, known as the fields of Forel; and ventral tegmental decussation in the midbrain
Foville, Achille-Louis-François	French Physician	Paramedian pontine syndrome of Raymond-Foville
Frey, Lucja	Polish Neurologist	Gustatory hyperhidrosis
Galen, Claudius	Roman Physician	Great cerebral vein
Gall, Friedrich	Swiss Neuroanatomist	Fasciculus gracilis (tract of Goll)
Gasser, Johann Laurentius	Austrian Anatomist	Sensory ganglion of the trigeminal nerve was named for him by one of his students, A.B.R. Hirsch
Gennari, Francesco	Italian Physician	White line in the visual cortex (stria of Gennari)
Golgi, Camillo	Italian Histologist	Type I and type II neurons; Golgi tendon organ; and Golgi apparatus
Gubler, Adolphe-Marie	French Physician	Ventral pontine syndrome of Millard-Gubler
Herophilus	Greek Physician	Confluence of the dural venous sinuses at the internal occipital protuberance is known as the torcular Herophili
Heschl, Richard	Austrian Anatomist And Pathologist	Transverse temporal gyri (Heschl's convolutions), for the auditory area of the cerebral cortex.
Heubner, Johann Otto Leonhard	German Pediatrician	Recurrent branch of the anterior cerebral artery
Hirschsprung, Harald	Danish Physician	Congenital aganglionic megacolon
Horner, Johann Friedrich	Swiss Ophthalmologist	Horner's syndrome, caused by interruption of the sympathetic innervation of the eye
Huntington, George Sumner	American General Medical Practitioner	Huntington's chorea resulting from neuronal degeneration in the corpus striatum
Kayser, Bernhard	German Ophthalmologist	Kayser-Fleischer ring in Wilson's disease
Klüver, Heinrich	American Psychologist	Klüver-Bucy syndrome caused by bilateral lesions of the temporal lobes
Korsakoff, Sergei Sergeievich	Russian Psychiatrist	Korsakoff's psychosis, in chronic alcoholism, includes a memory defect, and fabrication of ideas
Krause, Wilhelm Johann Friedrich	German Anatomist	Sensory endings in the skin, the end bulbs of Krause
Lanterman, A. J	American Anatomist	Incisures of Schmidt-Lanterman in myelin sheaths
Lissauer, Heinrich	German Clinical Neurologist	Dorsolateral tract of spinal cord (Lissauer's tract)
Luschka, Hubert von	German Anatomist	Lateral foramina of the IV ventricle (of Luschka)
Luys, Jules Bernard	French Clinical Neurologist	Subthalamic nucleus (nucleus of Luys)
Magendie, François	French Physiologist	Bell-Magendie law; and median aperture of the fourth ventricle (foramen of Magendie)
Martinotti, Giovanni	Italian Physician	Cells of Martinotti in the cerebral cortex
Meckel, Johann Friedrich	German Anatomist	Trigeminal ganglion is situated in Meckel's cave
Meissner, Georg	German Anatomist and Physiologist	Touch corpuscles in the dermis; and the submucous nerve plexus of the gastrointestinal tract
Merkel, Friedrich Siegmund	German Anatomist	Tactile endings in the epidermis (Merkel's disks)
Meyer, Adolph	American Psychiatrist	The fibres of the geniculocalcarine tract that loop forward in the temporal lobe constitute Meyer's loop
Meynert, Theodor Hermann	Austrian Neuropsychiatrist	Habenulointerpeduncular fasciculus (fasciculus retroflexus of Meynert); dorsal tegmental decussation of Meynert in the midbrain ; and nucleus basalis of Meynert is in the substantia innominata
Millard, Auguste Louis Jules	French Physician	Ventral pontine syndrome of Millard-Gubler
Monro, Alexander, II	Scottish Anatomist	Interventricular foramen between the lateral and third ventricles is known as the foramen of Monro
Nissl, Franz	German Neuropsychiatrist	Staining grey matter with cationic dyes to show the basophil material (Nissl bodies) of nerve cells

Name of the scientist / discoverer	Nationality	Anatomical structure named after
Pacini, Filippo	Italian Anatomist and Histologist	Sensory endings known as the Pacinian corpuscles
Papez, John Wenceslas	American Anatomist	Circuitry of the limbic system
Parinaud, Henri	French Ophthalmologist	Paralysis of upward gaze is due to a lesion of the midbrain, due to pressure from a pineal tumor
Parkinson, James	English Physician, Surgeon, and Paleontologist	"Shaking palsy" or paralysis agitans, which is more frequently called Parkinson's disease
Purkinje, Johannes (Jan) Evangelista	Bohemian Physiologist	Purkinje cells of the cerebellar cortex and Purkinje fibres in the heart
Ranvier, Louis-Antoine	French Histologist	Nodes of Ranvier in the myelin sheaths
Raymond, Fulgence	French Neurologist	Paramedian pontine syndrome of Raymond-Foville
Raynaud, Maurice	French Physician	Vasospasm, due to cold, decreases blood supply to limbs
Reil, Johann Christian	German Physician	Insula, or the island of Reil
Renshaw, Birdsey	American Neurophysiologist	Interneurons in the spinal cord are called Renshaw cells
Rexed, Bror	Swedish Neuroanatomist	Grey matter of the spinal cord into laminae of Rexed
Robin, Charles Philippe	French Anatomist	Perivascular spaces of the brain (Virchow-Robin spaces)
Rolando, Luigi	Italian Anatomist	Central sulcus of the cerebral hemisphere; and the substantia gelatinosa of the spinal cord
Romberg, Moritz Heinrich	German Clinical Neurologist	Romberg's sign of impaired proprioceptive conduction in the spinal cord
Rosenthal, Friedrich Christian	German Anatomist	Basal vein of Rosenthal
Ruffini, Angelo	Italian Anatomist	Sensory endings, known as the end bulbs of Ruffini
Schmidt, Henry D	American Anatomist and Pathologist	Incisures of Schmidt-Lanterman in myelin sheaths
Schultze, Max Johann	German Histologist and Zoologist	Comma tract or fasciculus interfascicularis of the spinal cord
Schütz, H	German Anatomist	Dorsal longitudinal fasciculus of the brain stem
Schwann, Theodor	German Anatomist	Neurolemmal (Schwann cells) of peripheral nerves
Sherrington, Sir Charles Scott	English Neurophysiologist	Reflexes; decerebrate rigidity; reciprocal innervation; and the synapse
Sydenham, Thomas	English Physician	Sydenham's chorea
Sylvius, Francis De La Boe	French Anatomist	Lateral sulcus of the cerebral hemisphere
Sylvius, Jacobus	French Anatomist	Cerebral aqueduct of the midbrain (of Sylvius)
Trolard, Paulin	French Anatomist	Greater anastomotic vein of Trolard
Vicq d' Azyr, Felix	French Anatomist	Mammillothalamic fasciculus
Virchow, Rudolph Ludwig Karl	German Pathologist	Perivascular spaces of the brain (Virchow-Robin spaces)
Wallenberg, Adolf	German Physician	Lateral medullary syndrome
Waller, Augustus Volney	English Physician and Physiologist	Degenerative changes in the distal portion of a sectioned peripheral nerve, known as wallerian degeneration
Weber, Sir Hermann David	English Physician	Midbrain lesion causing hemiparesis and ocular paralysis
Wernicke, Carl	German Neuropsychiatrist	Wernicke's sensory language area and Wernicke's aphasia are named for him
Westphal, Karl Friedrich Otto	German Clinical Neurologist	Edinger-Westphal nucleus in the oculomotor complex
Willis, Thomas	English Physician	Arterial circle of Willis
Wilson, Samuel Alexander Kinnier	British Clinical Neurologist	Hepatolenticular degeneration (Wilson's disease)
Wrisberg, Heinrich August	German Anatomist	Sensory root of the facial nerve (nervus intermedius of Wrisberg)

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Errata

PAGE NO.	INCORRECT WORDS	CORRECT WORDS
Page 7	Ischemic	Ischaemic
Page 20	Ischemic	Ischaemic
Page 42	Functional Imp ortance	Functional Importance
Page 47	Ischemia	Ischaemia
Page 123	Dieter's	Deiters'
Page 159	Dysdiadokokinesis	Dysdiadochokinesia
Page 216	Parabranchial	Parabrachial
Page 216	Fig 16.7 Parabranchial	Parabrachial
Page 223	Quenkenstedt’s	Queckenstedt’s
Page 229	Median eminence	Medial eminence
Page 230	Median eminence	Medial eminence
Page 232	Organ vasculosum	Organum vasculosum
Page 266	Ischemic	Ischaemic
Page 269	Dysdiadochokinesisa	Dysdiadochokinesia

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